MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

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A. A. COMMON, LL.D., F.R.S., President, in the Chair.

Hugh Lancelot Aldis, 67 Dieppe Street, West Kensington, W.;
William Ernest Cooke, M.A., First Assistant, Observatory, Adelaide, South Australia;
Alpin G. Fowler, M.Inst.C.E., 1 Cambridge Road, Norbiton;
David Edward Hadden, Alta, Buena Vista Co., Iowa, U.S.A.;
Rev. Robert Killip, Sale, near Manchester;
George Handley Knibbs, University, Sydney, New South Wales, Australia;
Frederick William McCarthy, 20 Chepstow Place, Bayswater, W.;
Charles J. Merfield, Department of Public Works, Sydney, New South Wales, Australia;
Captain Hugh Griffith Quirk, Baymount, Vico Road, Dalkey, co. Dublin,

were balloted for and duly elected Fellows of the Society.

The following candidates were proposed for election as Fellows of the Society, the names of the proposers from personal knowledge being appended:—

Thomas Edward Knightley, Architect, Clive House, Tulse Hill, S.W. (proposed by Edward Carpmael);
James Cavan, M.A., Eaton Mascott Hall, Shrewsbury (proposed by A. C. D. Crommelin).

Seventy-seven presents were announced as having been received since the last meeting, including amongst others :—

A. Fowler, Popular Telescopic Astronomy, presented by the publishers ; photographic enlargements from a negative of the Moon by MM. Lœwy and Puiseux, presented by Dr. L. Weinek ; lantern slides from Professor Keeler's drawings of *Mars*, 1892, presented by Mr. Newbegin.

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*Note on the Indexing of Scientific Papers.* By H. Seward, B.A.

In the present condition of scientific periodical literature the question of a subject-matter index is one of very great importance, and the necessity of some such work is yearly becoming more evident. As one who has had a large experience in indexing, especially in indexing of a scientific character, I venture to offer a few remarks on the subject, in accordance with the suggestion of the Secretaries in the last *Monthly Notices*.

First of all it is to be pointed out that a good index can only be made by an expert. It might be supposed that any person of ordinary literary or scientific attainments could make a satisfactory index, but everyone who has studied the subject knows that this view is entirely erroneous. Careful training in classification is absolutely necessary, and this is in most cases the work of years. From this it follows that the system (of indexing by authors), suggested by the Secretaries of the Royal Society, and tentatively adopted by our own Secretaries, can only be regarded as a very temporary one, and that it is one which is certain to break down in practice. The cause of the inevitable failure of this system is not so much the fact that authors often take a view of the importance of their own work which is not shared by their readers, but lies in the impossibility of obtaining uniformity by this method. Thus, to take a simple case : suppose papers on a total eclipse of the Moon are to be indexed, it will be found that these will be variously indexed under the words, "Total," "Eclipse," "Moon," "Lunar," by different authors (without counting such probable entries as "Colour of Eclipsed Moon," "Red Colour of Eclipsed Moon," "Earth's Shadow, Radius of," "Penumbra," &c., &c.), and the unfortunate compilers of an index will have to wade through masses of useless verbiage, meanwhile running the risk of missing something of importance. It can easily be seen that subject matter of a more complicated description, such as, say, "Measurements of the Wave Lengths of the principal lines in the Spectrum of *Nova Aurigæ* as determined by Photography," will lead us at once to hopeless confusion. We are thus drawn to the conclusion, which is, in fact, well known to trained indexers, that the first essential of an index is uniformity ; the same subject matter must always be

indexed in the same place. What this place is, is comparatively a matter of small importance. For instance, it matters little whether we index "Heliometers" under "Telescopes" or under "Micrometers," provided that all heliometers are indexed under one or the other heading, and not some in one place and some in another.

The next desideratum is to ensure as far as possible that one thing should be indexed in one place, and one place only. The object of this rule is to obtain the maximum of simplicity in the index. Unfortunately it is impossible to carry this out rigidly. It is obvious that such subject matter as "Photographs of Nebulæ" is of interest under both "Photography" and "Nebulæ," and that there will thus be many topics which will require indexing in more than one place. By means of a judicious system of "cross references," much of this repetition can be dispensed with, but there will always be a residuum of certain items which will need double or multiple indexing.

In order still further to obtain uniformity and simplicity, it will generally be found that a small number of indexers is more useful than a larger one. But be the number large or small, when once the general style of the index has been determined, the best practical plan is to draw up what may be called a skeleton index, *i.e.*, a list of headings and sub-headings to be used by the indexers, without any entries after the headings or sub-headings. This skeleton or "Key" index will at first be incomplete, and must be added to as occasion arises, care being always taken not to add anything which will be inconsistent with, or overlap, previously existing items. For this purpose the utmost possible accuracy and definiteness of statement is requisite. The wording of each heading and sub-heading must receive the most careful consideration; all ambiguous terms (such as "&c.") must be discarded; and when once a term has been decided on, no apparently synonymous one must on any account be allowed to take its place in the same heading or in related headings. One thing must always be called by one name, and one only. Besides the headings and sub-headings our "Key" must contain such cross references as are found necessary or desirable, though it is always well to cut down the number of these as far as possible, and also directions as to what subject matter is to be repeated under other headings. No radical or systematic alteration in this "Key" can generally be allowed unless under most exceptional circumstances. Of course with the progress of the science small alterations will frequently become desirable, but even these should be made very sparingly and only under extreme pressure.

The first and most useful practical step will therefore be the preparation of this skeleton index, for when once a working index has thus been obtained, three-fourths of the difficulties of indexing will disappear; it will be found that by far the greater number of items to be indexed will range themselves automatically under one or more headings or sub-headings. A few

cases only will remain which will require special treatment, usually by the addition of further cross references or new headings or sub-headings to the skeleton index. The utmost care must be bestowed on this "Key," as the facility in dealing with subsequent cases which is thus obtained will more than counterbalance a large amount of trouble in the original preparation. It would appear to be desirable to entrust the compilation of such a "Key" to a small committee, composed of men each with a special knowledge of some particular branch of astronomy, and all with sufficient enthusiasm for the science to take an interest in the little-regarded details of indexing. Such a committee could, with a comparatively small amount of work, achieve results the benefits of which would be felt by our science for many years to come.

We have only considered the question of the indexing of scientific papers in a general way; many of our conclusions may seem quite obvious, and others may seem to be based on unimportant details. The subject of indexing is so little understood, except by those who have had occasion to study it closely, that the importance of the considerations here advanced will probably not at first be admitted, but a very short practical experience will be sufficient to show the immense importance of the two points which we have laid down as essential, viz. *uniformity* and *simplicity*, and in order to carry out these essentials the plan of a skeleton index seems to be the most convenient and feasible one that can be adopted. The actual method of preparation of such an index is, of course, a matter for discussion, as to which many opinions may easily be maintained.

Until such a working index is, at any rate, in course of preparation, it would be well to defer further discussion with special reference to the science of astronomy; but it may perhaps be here noticed that it is very doubtful whether any index on such subjects as measurements of double stars, or observations of variable stars, can conveniently take the place of compiled catalogues such as we find in the published works of Burnham and others.

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*Note on a Crayon Drawing of the Moon by John Russell, R.A., at the Radcliffe Observatory, Oxford.* By E. J. Stone, M.A., F.R.S., Radcliffe Observer.

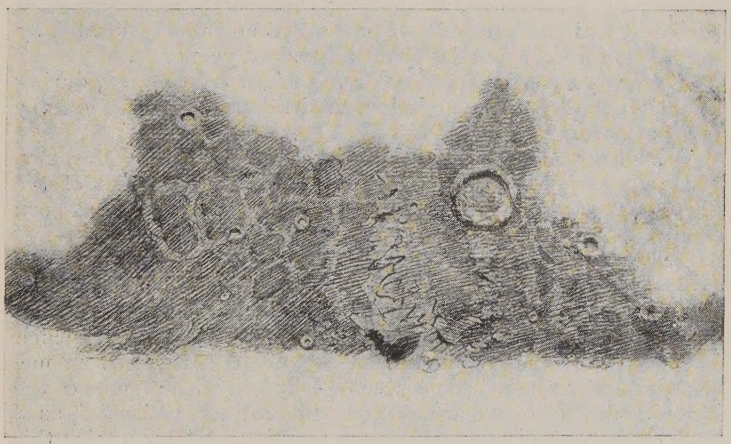
There is at the Radcliffe Observatory a crayon drawing of the Moon, made by the celebrated artist John Russell, R.A.

The drawing is 4 ft. 11 in. by 5 ft., and bears the date 1795. It is on paper stretched on canvas, and the paper is composed of sections carefully seamed together; the chief seam being across the centre. The surface is not *perfectly* flat.

Mr. Russell died in 1806 May; but the drawing did not

come into the possession of the Radcliffe Trustees until 1824 December.

When first received at Oxford the drawing was found to have been rather seriously damaged by wet on the journey. But Miss Russell, the artist's daughter—who was herself an artist, and trained in her father's methods—most kindly offered her assistance to restore the picture, and it was forwarded to her for this purpose. The drawing was returned to the Observatory on 1826 May 8, and it has remained there ever since.



Photographic reproduction of one of Russell's pencil drawings of Copernicus and its neighbourhood.

The crater Copernicus comes on the damaged portion of the drawing, and it would appear that Miss Russell, in her attempts at restoration, must have altered this part of the drawing, as it differs considerably from the original drawings of Mr. Russell of this crater, a copy of one of which is given above.

It appears that Mr. Russell's attention was first drawn to the desirability of the execution of drawings of the Moon by some skilled artist by Sir Joseph Banks, P.R.S. Mr. Russell was supplied with a six-inch reflector by Dr. Herschel, and he devoted to the work all the nights suitable for such work, which he could possibly spare, for nearly eighteen years.

A large number of detailed pencil drawings of different portions of the Moon's surface, made by Mr. Russell, are also in the possession of the Radcliffe Trustees; and many of them appear to me of an extremely interesting character.

The wet stains on the large crayon drawing, already alluded to, are principally on the blue background of the sky. They have always been visible since I have been at Oxford; but I have

thought that within the last year or two they have become more pronounced, and that there were clear indications of mildew. I have, therefore, dismounted the drawing, and had photographs of it taken : (1) in the state it was found before any attempts were made to remove the mildew or dust ; and (2) after the crayon drawing had been cleaned as far as I felt certain this could be carried out without damage.

These photographs have been taken by Mr. McClellan, an assistant at the Observatory.

I have thought that these photographs might be of some interest to the Fellows, as showing the general appearances of the Moon as it presented itself to the eye and was delineated by the hand of a skilled artist about a hundred years ago.

So far as I can judge, there are, as might be expected, during these hundred years, no distinct indications of change on the lunar surface.

I have appended a letter from Mr. Russell to Dr. Hornsby, which appears to me interesting, as giving some account of the views of the artist on such work. The original spelling has been retained.

Sir

I thank you for the fresh instance of your condescending goodnefs, in the Answer I am favor'd with to my last Letter, and your umerited willingnefs to give me afsistance ; which induces me to trouble you once more to read a Letter from me, containing my ardent Request to be indulged with a sight of the Drawing of Tycho you are so good to offer after Biachini, as I have never met with the Book you mention, which contains this and the Representation of other Spots in the Moon, with which I am somewhat acquainted as I have paid particular attention to these Spots, when the line of illumination falls directly upon them, by which I may receive considerable hints, and be enabled to determine, how much superior utility there is, in a Telescope of power considerably beyond the one I use, in deliniating the Moon ; of which I am not so fully convinced, by the Print which Monsr le Comte de Cafsini when in England inform'd me was drawn by means of the large Telescope in the Observatory at Paris.

I am greatly obliged by your observations respecting the Polar and Equatorial Diameters of the Moon, what I meant by the line of illustration, was the edge or boundary of illumination directly from the Sun ; and I was fearfull when I exprefs'd a considerable difference between the Polar and Equatorial Diameters, I might be supposed to have made the measure before the whole Moon was compleatly illuminated, therefore I exprefs'd myself as attending to the real Margin of the Moon in an early state, one side illuminated directly by the Sun, and the other by the Earths Reflection.

Pardon Sir my want of clearnefs.

*Woodburytype.* *E. & S.*

PHOTOGRAPH OF RUSSELL'S CRAYON DRAWING OF THE MOON, DATED 1795, AT THE RADCLIFFE OBSERVATORY, OXFORD.

LEEDS PHILOSOPHIC
AND LITERARY SOC

In answer to your question respecting my Work, "If it be only one large Map," I cannot help troubling you with the following. About twenty-five years since, I first saw the Moon through a Telescope, which I now recollect must have been about two Day after the first Quarter; you will conclude how much struck a young Man conversant with Light, and Shade, must be with the Moon in this state; especially, as I was not taught to expect such clearnefs and exprefsion, as is to be found near and upon the indented Edge; a few Days after I made a small Drawing, but the Moon being at the Full, I was not struck in the same manner, and I made no more attempts, till an accidental pofsefsion of a powerful Glafs awakened my attention to this beautiful Object once more, and for several years I have lost few opportunities when the Atmosphere has exhibited the Object of my study and imitation.

Before I began to deliniate the Moon I never saw any other representation, but the very inferior Prints to be met with in common Dictionarys, such unsatisfactory imitations, both as to incorrectnefs of Form and Effect, led me to conclude I could produce a Drawing in some measure corresponding to the Feelings I had upon the first sight of the gibbous Moon through a Telescope; that might give some pleasure to those who had view'd that Object attentively, for as to pecuniary profit, it was quite out of the question. After some succefsful attempts I met with two Maps in a Work by Joh$^{e}$ Bapt$^{a}$ Homanno, Norinbergæ, one was a copy of the full Moon by Hevelius the other after Ricciolus: upon the sight of these, I thought it was needlefs to prosecute the subject, they having more correctnefs in the parts than what I thought had been executed; but observing how little the Effect was produced (to speak as a Painter) I continued to divert myself. About a year after I met with the folio Volume of Hevelius and was again at a stand, but by this time I found that my experience had not only made me more expert in imitating what I saw, but my powers of discernment and discrimination were considerably improved, and I persued the subject with redoubled ardour, and I scarce lost a moment when the Moon was above the Horizon. About a year and half since I heard of the print after the Drawing by the late celebrated Astronomer Cafsini was publish'd in Paris. As I cou'd not but suppose the Work of so eminent a Profefsor with the powerful Telescopes of the French Observatory must pofsefs very superior excellence; who knowing what had been already done, could not employ himself without attempting very considerable improvements, however I still continued my persuit and employ'd a correspondent to procure me one of the Prints, but without succefs. On my return to London Mons$^{r}$ le Comte de Cafsini being in Town, who having heard of my Attempt favord me with a call, and indulged me with a sight of his celebrated Grand-Fathers Moon, in which I found my expectations were not disappointed, and that this Print as far exceeds all others which I

had seen in correctnefs and intelligence as it does in magnitude which is very considerable. But as you Sir would inform me, the Moon requires much attention to be well understood, being composed of so many parts, of different characters, so much similitude in each Clafs of forms, and of such a variety in the minutiæ composing those Forms and this difficulty also most considerably increas[d] by the various effects caused by the different situations of the Sun ; that I am perswaded many considerable improvements may be made, in correctnefs of Form in the spots, their situation and distinctnefs of parts ; perhaps it was too hastily concluded that the large dark parts upon the Moon's Face, were Seas ; I am apprehensive, that, if the Engraver has been faithfull to his trust, this must have led that great Astronomer Cafsini to represent these parts of one almost uniformly smooth, and uvaried effect, which upon a strict inspection will appear to be full of parts as various and nearly as multitudinous, as that portion of the Moon, which has generally been considerd to be Land, and is certainly elevated above the level of the former : even in the parts of the Moon which have been most considerd by Cafsini I think it will appear some considerable room is left for improvement. But there is a defiency which I have found in all these Maps of the Moon, and that is as I before hinted in point of Effect ; the just proportion is not maintain'd in the Gradations between the inherent Light and Dark parts of the Moon, by which all pleasurable distinctnefs of character is produced. It is by my attention to this circumstance, my attempts has given some satisfaction to those Gentlemen who have honord me by inspecting the preparatory Drawings.

It was my intention first to produce a representation of the Full-Moon as it is generally illuminated by the Sun, but several very respectable Astronomers favord me with their opinion, and by their approbation of one of my Crayon Drawings, which describes the Moon two days after the first quarter, very easily prevaild upon me to alter my resolution and prefer this in which the boldnefs and the exprefsive elevations of Plato, Copernicus, Tycho, and some others near the Boundary of the Line of illumination, convey so distinct an Idea of these parts opposed to those situated near the centre of the Moon which very faintly exprefs their character, compared to the former, as they are nearly lost in the general Blaze of Light. When this is compleated I mean to return to my first intention respecting the full Moon in which are to be seen a thousand pleasing particulars which I think have not been publish'd. And if my Life is prolonged I doubt not but my inclination will be to persue such other representations as may be thought most advisable.

Dr. Herschell honord me by suggesting the very same Idea with which I understand your last Favor advises, the representing the whole Face of the Moon in the manner of the internal edge of Light as described in the gibbous Moon which I have mention'd to have drawn with Crayons, composing one general

afsemblage from each days effect upon the boundary of Light where the Light and Shade are most exprefsive from the commencement to the full Moon or from thence to the end of the last quarter. I shall certainly attend to this advice with all that Respect which is due to such advisers : but I fear the advantage will not be so great as might be expected as I am apprehensive all that distintion of Dark and Light in the composition of the Moon, w$^{d}$ be lost, and also, that the Effect of elevations so pleasing and satisfactory in the edge of illumination in the Gibbous Moon, woud be indistinct and the whole appear very much confused ; as the agreeable effect is produced upon this Spherical Body, by the opposition of the parts distinctly seen near the edge to those which are more faint in the united mafs of Light, giving that satisfaction to the Eye which is produced in a picture well regulated by this conduct, a principle well know' among Painters and respected by connifseurs. There is a difficulty in executing the Moon upon this plan which I have endeavord to surmount but in vain : you will I hope Sir have the goodnefs to honor me with such instruction as you may think will afsist me respecting it, it is this, I know not how to exprefs upon this plan the parts of the New Moon till four days old or the four concluding days of the last quarter consistant with the rest, I hope my meaning will be understood when you consider the parts about Mare Crisium in the early stage of the Moon, they want that exprefsion which the rest have in the progrefsion of the Suns Rays, and which they have also a short time after the full Moon. The same is applicable to the parts about Grimaldus in the last quarter, I cannot conceive how these parts are to be renderd equally exprefsive with the rest unlefs one has the light represented as coming from the Right to the Left while the other are enlightend from the Left to the Right which must be extreamly improper. I apprehend those who have deliniated the Moon at least those whose works have come under my inspection, may have proceeded upon a plan different from that which I have adopted, and what at first sight appears the most Eligible, that of determining the parts with their situations with correctnefs at the first, and then of adding the different degrees of strength to the Outline by which means they have left this material persuit the Effect of the whole together particularly imperfect, and from the embarrasing multitude of Lines some considerable mistakes have been made, in that part of the work which to them must have been considerd as the most important, viz. the size of the Spots their distance from each other and their exact situation which can be demonstrated, but wou'd add so considerably to my prolixity for me to attempt, as to add to my confusion in trespafsing more upon your Time, by that which is already so very prolix and I fear not free from an impertinent appearance.

My first efforts Sir were made with Crayons, representing the colour of the Moon in its general form according to the particular Phase, upon this I laid the larger Spots of Mediteraneum

Serenitatis Tranquilitatis &c &c—these I adjusted by degrees giving them their general Forms and grand bearings endeavouring to preserve with as much truth as time would admit the proportional difference of dark & Light; by which one part is subordinate to the other; and proceeding so long as the Moon was to be seen: executing the minutiæ as far as time would permit, being always attentive to the most considerable parts before those which are subordinate. The Effect of the Moon thus produced, surrounded by a dark Blue colour has a novelty as well as an exprefsion in its appearance, which has given some pleasure to many Gentlemen whose approbation is very flattering to me. But I am very sensible that in a Drawing of fourteen inches Diameter the crayons such as I use are not proper to exprefs the minutiæ with accuracy however proper for the effect they may be, I have therefore contented myself by making that part which was in my power something correct. I used other means in drawing the parts which are more minute, the fine point of a black Lead pencil I think the best for the purpose and have furnish'd myself with a great number of Drawings in this manner, of the different Spots in the Moon under the circumstances they present themselves in the different Phases, from these Drawings and in continual reference to the Moon itself, I am proceeding upon the larger picture, producing the effect from the Drawings made with Crayons and the small parts from those with black lead pencils.

As a painter it is no vanity for me to say, much may be done in regard to accuracy by the Eye only afsisted by the Telescope. We are used to consider the size, form and proportion of parts, it is the first principle of our Art, it must be acquired; but I have not presumed upon this imaginary power of correctnefs, the Eye is capable of being deceiv'd, and as I want to approach as near as may be to perfection, I am induced to measure the distances of as many parts as will set the rest in their proper places. As I have no micrometer such as would describe minutes &c. and if I had, thro' my inexperience and want of sufficient power of calculation, I should be embarrafs'd thro' the Moon's Variation in its Diameter, at different times. I have constructed one which serves my purpose. A hair is strain'd in the Focus of the short Tube of my Telescope, upon this Hair is made marks of different sizes and at various distances. A scale upon paper has been fixt upon a wall at a certain distance, and by this scale I have afsertain'd the size of the Marks and the Space which separates each from the other: a counter scale proportion'd to work the large picture with, is all I need to keep my mind satisfied that I do not proceed in Vain for I have by a particular method prevented the inconvenience which the want of a crofs Bar and perpendicular would otherways have occasion'd.

It will be some time before I have compleated my intention, as I have many engagements and this I only esteem as my

amusement. I do not promise to present my efforts to the public, that must depend upon circumstances.

That with which you conclude your Letter has not escaped my notice. The Libration of the Moon from North to South as well as from East to West. I am much obliged to you Sir for this and the other observations, in which you have freed me from my embarrafsments. I hope to be pardon'd if when other difficulties arise I am constrain'd to make application for your instruction.

I have the honor to be with very great Respect
Sir
Your very much obliged
and most obedient
humble servant
John Rufsell.

*Mortimer Street*
*Feb*$^{y}$ 19, 1789.

## *Details of the Total Solar Eclipse of* 1896 *August* 8–9 *for Kushiro, in the island of Yezo.*

(*Communicated by the Superintendent of the "Nautical Almanac."*)

The following details are communicated to the Society, as it is understood that Kushiro has been selected as one of the stations to be occupied by the observers of the Joint Permanent Eclipse Committee, who are going out to Japan next August. Should a second station be selected within fifty or sixty miles of Kushiro, the circumstances of the eclipse for it can be computed, with sensible accuracy, from the subjoined equations.

The details for Horonai, on the N.E. coast of Yezo, will be found in *Nautical Almanac Circular*, No. 15.

The elements adopted in the computations are those published in the *Nautical Almanac* for 1896, p. 416.

Assumed position of Kushiro... ... Long. 144° 22′ E., Lat. 42° 58′ N.
(reduction to $l-11''\cdot7$)

| | d | h | m | s | Contact from N. Point. | Contact from Vertex. | Sun's Altitude. |
|---|---|---|---|---|---|---|---|
| Eclipse begins Aug. | 9 | 2 | 6 | 46 | 55° W. | 94° W. | 53° |
| Totality begins „ | 9 | 3 | 16 | 52 | Duration $2^{m}\ 35^{s}\cdot5$ | | 42° |
| Totality ends „ | 9 | 3 | 19 | 27 | | | |
| Eclipse ends „ | 9 | 4 | 23 | 44 | 123° E. | 73° E. | 30° |

Local mean times and *direct* image.

For any place not far distant the geocentric north latitude being $l$, and east longitude $\lambda$, the Greenwich mean time $t$ of

partial beginning may be approximately computed from the following formulæ :—

$$\cos\omega = +1{\cdot}12272 - [0{\cdot}16735]\sin l + [0{\cdot}05786]\cos l\cos(\lambda - 46^\circ\ 10'{\cdot}9)$$
$$t = \text{Aug. } 8^{\text{d}}\ 17^{\text{h}}\ 38^{\text{m}}\ 15^{\text{s}} - [3{\cdot}65074]\sin\omega - [3{\cdot}65552]\sin l - [3{\cdot}84426]\cos l\cos(\lambda - 12^\circ\ 40'{\cdot}8)$$

Contact on ⊙'s limb, $\omega - 34^\circ\ 31'{\cdot}1$ from the N. point towards the W.

and the Greenwich mean time of partial ending by—

$$\cos\omega = +1{\cdot}52241 - [0{\cdot}18107]\sin l + [0{\cdot}03061]\cos l\cos(\lambda - 14^\circ\ 21'{\cdot}7)$$
$$t = \text{Aug. } 8^{\text{d}}\ 17^{\text{h}}\ 12^{\text{m}}\ 18^{\text{s}} + [3{\cdot}57870]\sin\omega - [3{\cdot}55219]\sin l - [3{\cdot}78268]\cos l\cos(\lambda + 19^\circ\ 13'{\cdot}1)$$

Contact on ⊙'s limb, $\omega + 31^\circ\ 48'{\cdot}0$ from the N. point towards the E.

Also the Greenwich mean times of the beginning and ending of totality may be approximately computed from the following formulæ in which the upper sign applies to the beginning, and the lower sign to the ending :—

$$\cos\omega = +70{\cdot}69521 - [1{\cdot}88965]\sin l + [1{\cdot}76504]\cos l\cos(\lambda - 29^\circ\ 43'{\cdot}0)$$
$$t = \text{Aug. } 8^{\text{d}}\ 17^{\text{h}}\ 19^{\text{m}}\ 17^{\text{s}} \mp [1{\cdot}89913]\sin\omega - [3{\cdot}61011]\sin l - [3{\cdot}81343]\cos l\cos(\lambda + 3^\circ\ 38'{\cdot}3)$$

The quantities in square brackets are logarithms, those in the second equation of each pair being logarithms of seconds of time.

"*Nautical Almanac*" *Office :*
1896 *January* 2.

*On the Proper Motion of* $\mu$ *Cassiopeiæ.* By W. T. Lynn, B.A.

In the upper part of the left arm of *Cassiopeia*, Bayer has marked two stars, but appears to have inadvertently omitted to letter the brighter one on his map of the constellation. But from the subsequent letterpress it is clear that he intended to indicate it by the letter $\theta$. The fainter star in its immediate proximity he marked by the Greek letter $\mu$. This latter star has long been well known to be endowed with a large proper motion in both elements, whilst the proper motion of $\theta$ is very small. In some future age it may perhaps be found that $\mu$ is in orbital motion round $\theta$, and a very gigantic motion this would be. No attempt has yet been made to determine the parallax of the latter ; but the late Professor Pritchard obtained an approximate measurement of that of $\mu$ by the photographic method, the result being (value found, $0''{\cdot}04$), that its large proper motion is not due to any special proximity.

Bessel long ago showed that this proper motion was essentially confirmed by the observations of the star made by Tycho Brahé. My present object is to deduce its accurate value, from those which have been obtained, chiefly at Greenwich, during the last fifty years. Below are tabulated the results from the Twelve-Year, Seven-Year for 1860, Nine-Year and Ten-Year Greenwich Catalogues (no observations of the star were made in the periods covered by the Six-Year and the second Seven-Year Catalogues), and the latest Radcliffe Catalogue, which is reduced to the epoch of 1890.

| Catalogue. | Epoch. | R.A. h m s | N.P.D. ° ′ ″ |
|---|---|---|---|
| 12-year | 1840 | 0 57 40·42 | 35 52 2·68 |
| „ | 1845 | ... | 35 50 34·38 |
| 7-year | 1860 | 0 58 58·93 | 35 46 5·77 |
| 9-year | 1872 | 0 59 46·205 | 35 42 30·10 |
| 10-year | 1880 | 1 0 17·736 | 35 40 8·15 |
| Radcliffe | 1890 | 1 0 57·167 | 35 37 10·15 |

The differences between these (omitting the observations, in one element only, of the second part of the Twelve-Year), are

| | In R.A. m s | In N.P.D. ′ ″ |
|---|---|---|
| 20 years | +1 18·51 | −5 56·91 |
| 12 years | +0 47·275 | −3 35·67 |
| 8 years | +0 31·531 | −2 21·95 |
| 10 years | +0 39·431 | −2 58·00 |

From these result the annual changes—

| | In R.A. s | In N.P.D. ″ |
|---|---|---|
| 1840–1860 | +3·926 | −17·846 |
| 1860–1872 | +3·940 | −17·972 |
| 1872–1880 | +3·941 | −17·744 |
| 1880–1890 | +3·943 | −17·800 |

Now the precession during the successive periods may be taken as $+3^{s}\cdot537$, $+3^{s}\cdot548$, $+3^{s}\cdot554$, and $+3^{s}\cdot560$ in R.A., and $-19'\cdot410$, $-19''\cdot388$, $-19''\cdot370$, and $-19''\cdot356$ in N.P.D. Subtracting these, we obtain for the proper motion—

| | In R.A. s | In N.P.D. ″ |
|---|---|---|
| 1840–1860 | +0·389 | +1·564 |
| 1860–1872 | +0·392 | +1·416 |
| 1872–1880 | +0·387 | +1·626 |
| 1880–1890 | +0·383 | +1·556 |

All these results are derived from a considerable number of observations, and the mean result, $+0^{s}\cdot3878$ in R.A. and $+1''\cdot540$ in N.P.D., is probably a very accurate value of the proper motion of this star. It differs slightly from that adopted in both the Greenwich Ten-Year Catalogue and the Radcliffe Catalogue for 1890, which is $+0^{s}\cdot3860$ in R.A. and $+1''\cdot580$ in N.P.D.

We will now compare the latest place, that given in the Radcliffe Catalogue, with that deduced from Bradley's observations, as given in Professor Auwers's *Neue Reduction*. The place in the latter, which is for the epoch 1755, is R.A. $0^{h}\ 52^{m}\ 9^{s}\cdot59$, and declination $+53°\ 42'\ 35''\cdot5$=N.P.D. $36°\ 17'\ 24''\cdot5$. From this, by the aid of the successive precessions given by Auwers and that in the Radcliffe Catalogue (all founded on Struve's constant), we obtain for Bradley's place, reduced to 1890,

R.A. $1^{h}\ 0^{m}\ 5^{s}\cdot01$, N.P.D. $35°\ 33'\ 38''\cdot70$.

The actual place for this date, as given in the Radcliffe Catalogue, is

R.A. $1^{h}\ 0^{m}\ 57^{s}\cdot167$, N.P.D. $35°\ 37'\ 10''\cdot15$,

differing from the former by $+52^{s}\cdot157$ and $+3'\ 31''\cdot45$. The difference between the two epochs being 135 years, this gives for the annual proper motion $+0^{s}\cdot386$ in R.A., and $+1''\cdot566$ in N.P.D. ; a result in very satisfactory agreement with that which I have deduced above from the later Greenwich and Radcliffe Catalogues.

*Blackheath:* 1895 *December* 9.

*Description of a Spectroscope (the Bruce Spectroscope) recently constructed for use in connection with the 25-inch Refractor of the Cambridge Observatory.* By H. F. Newall, M.A.

The spectroscope which is described in the present note has lately been constructed for use in connection with the 25-inch visual refractor (the Newall telescope) of the Cambridge Observatory.

It has been arranged solely for photographing spectra, and no provision has been made for visual micrometric measurements.

In designing the spectroscope, and especially in deciding on what may be described in general terms as a single-prism spectroscope, I have been guided by the following considerations. The brighter stars in the northern hemisphere have been studied in considerable detail, and provision has been made for their being further studied at many observatories. A new instrument to be used in connection with an equatorial of large light-collecting

power should be designed chiefly with a view to rendering work of high precision possible in the case of the fainter stars. For work of high precision it seems best at present to adopt a spectroscope with collimator and slit, and to provide arrangements for getting comparison spectra from terrestrial sources.

In the case of faint stars, the primary difficulty is to get a photograph at all, however little the purity or definition of the spectrum. It is therefore of the greatest importance to adopt arrangements which involve as little loss of light as possible in the spectroscope itself, and which ensure that as much as possible of the light collected by the object-glass of the equatorial shall pass into the slit of the spectroscope.

Preliminary work with spectroscopes of various constructions has shown that it would be necessary to modify the colour correction of the visual refractor by some auxiliary lens, or else to put up with a very limited range of spectrum. The difficulties which arise in consequence of imperfect achromatism, in spectroscopic investigations made in connection with large refractors, have been described by many observers ; most recently by Keeler with reference to the Lick telescope (*Astroph. Jour.* 1895, I. p. 102), and by Belopolsky with reference to the Pulkova refractor (*Astroph. Jour.* 1895, I. p. 366).

The spectroscope may be briefly described as having a single large white-flint prism, transmitting a beam of light of circular section and 2 inches in diameter, and having a camera of fixed length, in which may be used either (1) an ordinary object-glass for giving a short spectrum of a very faint star, the spectrum being in this case 19·9 mm. long from $H_\beta$ to midway between H and K, or (2) a telephoto-combination arranged so as to effectively double the length of the camera for giving a greater linear dispersion for medium stars, the spectrum being in this case 44·5 mm. long for the same range as above stated.

It is perhaps of interest to record here the linear extent of the spectrum from $H_\beta$ to midway between H and K (the same range as above) for some of the spectrographs lately used by Dr. Vogel at Potsdam (*Astroph. Jour.* 1895, p. 200).

| | |
|---|---|
| No. I., used for velocity in line of sight, | 69· mm. |
| No. II., used for spectra of *Mars* or *Jupiter*, | 16· mm. |
| No. III., used for *Nova Aurigæ*, | 7·0 mm. |
| No. IV., used for *β Lyræ*, | 8·6 mm. |

The mode of attachment to the refractor is, I believe, unusual, and may be briefly described as follows :—

A correcting lens is inserted in the cone of rays coming from the object-glass of the refractor. It is set about 5 feet from the uncorrected focus ; and the corrected focus is nearer to the object-glass by about 18 inches. (The effective focal length of the combination is about $20\frac{1}{2}$ feet.) The corrected focus is thus drawn up inside the refractor.

The spectroscope is pushed up partly into the tube of the refractor so that the slit coincides with the corrected focus.

In this arrangement many advantages are gained, notably the following :—

(1) An improved colour correction results.
(2) Strength is gained in the attachment of the spectroscope to the eye-end.
(3) Space is economised, for the spectroscope is 18 inches nearer to the object-glass of the refractor.
(4) The whole spectroscope, being attached to a strong framework which is clamped to the focussing tube of the refractor, can be moved bodily in and out (for the purpose of focussing the star on the slit) without altering the adjustment of the parts of the spectroscope.
(5) The convergency of the cone of rays from the object-glass of the refractor can be arranged to have a very convenient value ; the convergency for the uncorrected object-glass is about 1 in 14·0, and with the correcting lens it becomes 1 in 10.
(6) As a consequence of the altered convergency, the requisite resolving power can be attained in the single prism with shorter collimator.

The one drawback that I realise at present is that, since the relation between the purity P, the resolving power R, and slit width $s$, and the ratio $\psi$ of aperture to focal length, is

$$P = \frac{\lambda}{s\psi + \lambda} R,$$

it is clear that the slit-width must, for a given purity and resolving power, vary inversely as $\psi$. This I regard as a great disadvantage ; but it has seemed to me that there was a balance of advantage in favour of the lens.

I was at first inclined to think that the inaccessibility of the slit was an insuperable objection. But the adoption of Huggins' admirable plan of a reflecting slit-plate has got over all the anticipated difficulties.

Having thus briefly indicated the general method adopted, I proceed to describe some of the details.

*The Eye-end or Breech-piece of the 25-inch Refractor.*

No doubt many of the conveniences of the adopted method of attaching the spectroscope depend on the arrangement of the eye-end of this special refractor. The sturdy massiveness of Cooke's work has formed a splendid foundation, to which the spectroscope has been fitted.

The steel tube of the refractor is cigar-shaped, wider in the middle than at the ends. At the eye-end the steel tube has a diameter of 21 inches, and to it is fitted a strong iron casting

THE EYE-END OF THE NEWALL TELESCOPE WITH THE SPECTROSCOPE ATTACHED.

*(The two-foot rule hanging near the lower finder gives the scale, 1 inch to the foot.)*

which contracts the opening with a rapid taper down to $8\frac{1}{2}$ inches, and forms a strengthening piece with a turned flange. Into the opening thus left is fitted a massive breech-piece (an arrangement of draw tubes, position circle and focussing mechanism), ending in a flange with a kind of bayonet joint, to which the various adapters for eye-pieces, micrometer solar eye-pieces, &c., can be fitted. All apparatus fitted to the bayonet joint can be rotated in connection with the position circle, and can be racked in and out by means of the focussing screw through a range of 4 inches. The breech-piece weighs about $1\frac{1}{2}$ cwt., and its weight gives an idea of its strength. It is to this bayonet-joint flange, the aperture of which is $5\frac{3}{4}$ inches in diameter, that the spectroscopic appliances are attached. The plane of the flange, when racked in as far as the focussing screw will take it, is about $7\frac{3}{4}$ inches nearer to the object-glass than the uncorrected focal plane.

*The Correcting Lens.*

A simple convexo-concave lens of aperture 5 inches, and of focal length 154 inches for light of wave-length 5890–6 λ is set in the convergent beam of rays coming from the object-glass of the refractor at a distance of about 62 inches from the focus, or, as I shall now call it, the uncorrected focus. The corrected focus is about 18 inches nearer to the object-glass.

The lens is mounted at the end of a brass tube, and the other end of the tube is provided with a heavy flange. The tube is pushed, lens first, into the refractor, and the flange is clamped into the bayonet joint at the end of the breech-piece.

The position of the lens can be altered by the focussing screw, but when the lens is pushed in as far as it will go, then the new, or corrected, focus is inside the tube which holds the correcting lens about 11 inches from the new flange on the breech-piece.

It is unnecessary to go into details concerning such a lens, inasmuch as Keeler has recently published (*Astroph. Jour.* 1895, i. p. 101) a note on work which is in great measure identical with that which I undertook in considering the possibility of getting a satisfactory improvement of the colour curve with a simple lens. Keeler has rejected the solution "for the general case of large telescopes," on the ground that the alteration which the use of such a lens would produce in the aperture of the convergent beam (*i.e.* the ratio of the diameter of the cross section of the convergent beam to the distance of the cross section considered from the focal plane) is excessive. In the case he considers the ratio is altered from 1 : 19 to 1 : 5, and this would involve the use of a collimator of such unusual proportions as to be impracticable.

But the question is—is it possible to produce a considerable change in the colour correction without excessive change in the ratio referred to? Elementary calculations, similar to those published by Keeler, showed that it was worth while to have a lens

made, and experimental determinations of the corrected separation of the foci for different colours for the actual correcting lens used have convinced me that the improvement is considerable. It is clear that if the separation of the foci were reduced only in the same proportion as the convergency ratio, no advantage would be gained ; when one of two colours was in focus on the slit the circle of aberration for the other colour would be just as great as without the correcting lens.

My lens is arranged to give a convergent beam, with ratio 1 : 10, whilst the uncorrected object-glass has a ratio 1 : 14·0. Under these circumstances the collimator of the spectroscope is of very convenient dimensions—namely, 2 inches aperture and 20 inches focal length. A comparison of the diameter of the circles of aberration on the slit, first for the uncorrected object-glass and second for the corrected object-glass, shows clearly the advantage gained. If the light focussed on the slit in each case is light of wave-length 4860 λ ($H_\beta$), the circles of aberration deduced from actual measurement for $H_\gamma$ and $H_\delta$ have diameters as follows :—

| | Uncorrected O.G. mm. | With Correcting Lens. mm. |
|---|---|---|
| $H_\beta$ | 0·00 | 0·00 |
| $H_\gamma$ | 0·81 | 0·36 |
| $H_\delta$ | 1·94 | 0·97 |

Photographs of star spectra are satisfactorily uniform from λ 5896 (D) to λ 4470. I refer here to uniformity of density ; in another place I give suggestions as to a cause of unsatisfactory definition at the ends.

The following point with respect to the focussing of the star on the slit may be noted. The distance between the slit and the correcting lens is fixed when the collimator is clamped in the framework. The focussing is accomplished by moving both spectroscope and correcting lens simultaneously in or out by means of the focussing screw. The distances between the correcting lens and the conjugate foci are so related that the movement of the lens and spectroscope through any given small distance produces a movement of the star-image through nearly exactly one-half that distance with respect to the slit. The focussing, which is of great importance, can thus be done with great accuracy.

### *The Framework of the Spectroscope.*

The frame of the spectroscope consists of a heavy hollow conical casting of gun-metal with a flange at each end. The larger flange is that by which the whole spectroscope is clamped to the equatorial by means of four large thumb-screws ; to the smaller flange is attached a strong ribbed aluminium casting, carrying the pivots about which the whole camera can turn, and between which the prism is mounted.

*Description of Plate.*

A Small red lamp to illuminate slit and guiding comb.
B Comparison prisms.
C Mirror to reflect light into guiding eye-piece.
D Plane through slit.
E Flange by which spectroscope is attached to equatorial.
F Tube to which are fitted the apparatus for comparison sparks, &c.
G To move guiding comb in front of slit.
H To view slit for guiding during exposure.
I To widen slit.
J To adjust prism.
K To focus collimator.
L To move comparison prisms.
M Prism.
N To focus camera.
O To clamp camera.
P Thermometer.

The collimator is held in the conical casting, the lens projecting through a hole in the smaller flange and the aluminium casting, and the plane of the slit being about 11 inches from the plane of the larger flange. The whole collimator is arranged to slide through a small range (about $\frac{1}{2}$ inch) so that the distance between the slit and the flange may be adjusted. The final focussing of the star-image on the slit is accomplished by moving the whole spectroscope in or out by means of the large focussing screw on the breech-piece.

About midway between the flanges on the conical casting the casting is thickened, so that a cylindrical ring is formed which facilitates the attachment of several accessory arrangements: (i) a telescope and reflectors to enable the observer to view the slit as from in front; (ii) condensing lenses and reflectors to throw an image of a spark or tube for comparison spectra upon the slit; (iii) a clamping-screw to hold the stay-rods by which the camera is prevented from turning about the pivots; and several other small things which it is not necessary to specify.

*The Collimator and Slit and Guiding Comb.*

The collimator has a focal length of $20\frac{1}{2}$ inches (520 mm.) and an aperture of $2\frac{1}{8}$ inches (54 mm.), the object-glass being a visual achromatic.

The stout collimator tube is made so that it can slide through a small range in the frame of the spectroscope; and when the tube is clamped in position the object-glass can be moved relatively to the slit by means of a rack and pinion. A scale is attached by which the focus-reading can be read off.

The slit is arranged after the admirable device of Dr. Huggins. The jaws are made of speculum-metal, and the exposed faces are highly polished, so as to form a single plane surface, which is inclined at a small angle to the axis of collimation. Great care was taken to work the sharp edges in a proper manner.

When the image of a star is thrown upon the slit, some portion of the light passes through the slit; the rest is reflected by the polished faces of the jaws on to a small mirror, fixed in front of the slit and displaced slightly to one side, so as not to interfere with the incident pencil. The mirror, together with a system of lenses and a reflecting prism, enables the observer to view the slit: he looks into an eyepiece attached to the conical framework in a direction perpendicular to the axis of the collimator, and sees the slit and any images (whether of star or of spark for comparison spectra) that may fall upon it from the proper quarter.

In front of the slit is set a small movable guiding comb, which enables the observer to set the star-image on any required part of the slit. The teeth of the comb cover certain parts of the slit, and leave the rest exposed. By a suitable mechanism the comb can be either moved by a very small amount up and down the slit, or altogether withdrawn so as to expose the whole

slit. By making the teeth of the comb twice as wide as the gap between them, it is arranged that three spectra can be set side by side—*e.g.* a star spectrum taken between two spark spectra, one of which is taken before, the other after, the star spectrum. In this mode of procedure any changes of adjustment that may have arisen during the exposure for the star spectrum, in consequence of change of temperature or in the position of the spectroscope, may be at once detected in the photograph.

The beautiful device of Dr. Huggins's reflecting slit is only open to one objection, so far as I am aware. Let us suppose it is desired to investigate a spectrum near Hγ. In this case it is necessary to focus Hγ-light on the slit and to keep it on the slit. It is difficult to do this, in consequence of the chromatic aberration of the equatorial; but the following device has proved efficacious. From time to time the star is observed on the slit with a small direct-vision compound prism held between the eye and the guiding eyepiece in such a way that the length of the spectrum is parallel to the length of the slit. The slit then appears as a fine dark line running along the length of the spectrum, which is narrow at the part or parts focussed on the slit, and has at any other part a width determined by the diameter of the circle of aberration of the light corresponding to that part. The star is then moved until the narrow parts of the spectrum fall on the slit. The prism is then removed, and the position of the slit with respect to the slightly blurred star-image is noted, so that guiding can be continued with only occasional recourse to the prism.

In such work as the investigation of the spectrum of special parts of a planet or a nebula the reflecting slit is invaluable.

### *The Prism.*

The prism at present used is a white dense flint prism of 60°. The height is $2\frac{1}{8}$ inches (54 mm.), and the length of the side of the triangular section is $3\frac{3}{8}$ inches (86 mm.).

The resolving power for λ 5896 is about 7600; $\delta\lambda = \cdot 8$ tenth-metre.

" " λ 5000 " 12000 " ·4 "

" " λ 4250 " 22000 " ·2 "

The edges and angles of the prism are all ground blunt, and the prism is partly encased in aluminium sheet, which is bent so as to cover the triangular faces (the "top" and the "bottom") of the prism and also the ground rectangular base, but so as to leave the two polished rectangular faces free. Two small gun-metal bosses are fitted to the aluminium case, one fixed on the bottom, the other being adjustable within small limits on the top of the prism. Fine centre-holes are drilled through the bosses and the line joining them is made parallel to the refracting edge, the final adjustment being made by moving the adjustable boss by four screws. Two screws with fine conical points pass through the pivots about which the camera turns, and the prism is held in its

case between these conical points or male centres, which are screwed through the pivots into the female centres in the bosses. The prism thus held is free to turn about an axis through the male centres. An arm projecting from the top of the prism-case is pressed by a spring against the end of a screw which is fixed to the frame-work, and a slow motion for adjusting the prism for minimum deviation is thus provided.

This mode of holding the prism has proved very satisfactory. The slit at the end of the collimator is adjusted to parallelism with the line joining the male centres, and this ensures parallelism with the refracting edge of the prism, provided that the line through the female centres has been adjusted.

*The Camera.*

The camera is made of a brass tube about 10 inches long joined rigidly to a tapered box of rectangular section, made of aluminium sheet and having a length of 10 inches. The total length of the camera is thus 20 inches.

The following object-glasses can be used in it, each having an aperture of $2\frac{1}{8}$ inches (54 mm.).

(1) A visual achromatic object-glass of focal length 20 inches (508 mm.).

(2) A plano-convex quartz lens of focal length 20 inches. The use of an uncorrected lens of this kind is convenient when flat photographic plates are used. With two similar achromatic lenses in the collimator and camera, the result of the over-correction of both lenses is to give a spectrum which cannot be in focus over a considerable range unless a curved plate or film is used. If an uncorrected lens is used in the camera in connection with an over-corrected lens in the collimator, the spectrum is flatter. Whether it is better to use glass or quartz for the simple lens depends upon the character of the colour correction of the achromatic object-glass used in the collimator.

In laboratory work I have used a spectacle lens of 36 inches focal length in connection with an over-corrected "achromatic" collimating lens and have got admirable spectra from the D lines to the λ 3800 photographed in sharp focus on a single flat plate without tilting the plate. I have not seen the method described, but it is so simple that it is most probably known.

(3) A telephoto-combination, designed and used in such a way as to have an equivalent focal length of about 40 inches (1016 mm.) though the extreme *actual* length of the camera is the same as with the other object-glasses, namely 20 inches (508 mm.).

The use of this optical device was only decided upon after numerous experiments, and I take this opportunity of expressing my obligations to Messrs. Dallmeyer for their kindness in letting me try some of their combinations before having a pair made for use in this spectroscope.

If justification of the use of this method be required, it may be based on the following considerations. The prism used is of such dimensions that the resolving power is considerably higher than that which a photographic film with its markedly granular structure can ever do justice to. The theoretical resolving power of my prism is a little more than one of Professor Vogel's compound prisms. Professor Vogel * has expressed the opinion that the performance of his prisms would have warranted a large increase in the focal length of the camera, but such an increase would have increased the linear dispersion so much that only the brightest stars could have been observed with the Potsdam Refractor. The question therefore presents itself: Is it better to use two prisms and a short camera or one prism and a long camera? The only considerations which bear on the point are practical, and it appears to me that the coarseness of granularity of available photographic plates is the most important factor; for it would seem useless to employ an optical resolving power greater (except by an arbitrary amount for margin) than the defining power of the photographic plate. If the necessary resolving power can be attained with a single prism of manageable dimensions, the balance is in favour of the single prism, for it involves a smaller loss of light.

*Scales on the Instrument.*

The importance and convenience of having scales on the instrument, by which every adjustment of every adjustable part can be recorded, cannot be over-estimated.

The following scale readings are taken for each exposure made on the telescope.

1. Position angle of the slit, usually 90°.
2. Focus reading, localising the position of the slit amongst the coloured images of the star formed on the collimation axis of the equatorial.
3 and 4. Focus readings of the collimator and camera.
5. Inclination of the photographic plate.
6. The inclination of the axes of camera and collimator.
7. Width of the slit.
8. Temperature recorded by a thermometer attached to the camera.
9. The part of the slit exposed at different times during any exposure.

There is still needed a tenth scale to record the position of the prism.

*Some Numerical Details.*

The weight of the spectroscope is 26 lbs.; the weight of the flanged tube which holds the correcting lens, 13 lbs.

Assuming, for the sake of definiteness, that determinations of radial velocity would be made by measurements near $H_\gamma$, the

* *Publn. d. Astroph. Obs. zu Potsdam*, 1892, vol. vii. pp. 20 and 21.

following details give a more precise idea of the conditions under which such measurements could be made with the spectroscope described in this note.

The spectrum near $H_\gamma$ has a linear dispersion 1 mm. to 21 λ (tenth-metres). Taking the minimum measurable quantity to be $0^{mm}\cdot001$, this would correspond to $0^{\lambda}\cdot021$, or to 1·5 km./sec., or 0·9 mile/sec. (In Vogel's classical researches, $0^{mm}\cdot001$ corresponded to $0^{\lambda}\cdot013$, or 0·9 km./sec., or 0·6 mile/sec.)

The diameter of the first diffraction ring in the corrected image formed by the object-glass of the equatorial and the correcting lens is, for $H_\gamma$, $0^{mm}\cdot011$.

Near $H_\gamma$, since the resolving power of the prism is 22000, the purity of the spectrum can never be advantageously greater than 7000. The following table shows the relation between the purity and the slit-width.

| Purity. | Slit-width. mm. | Spectrum pure enough to separate two lines for which δλ is |
|---|---|---|
| 7300 | 0·0086 | 0·60 tenth metre |
| 5500 | 0·025 | 0·79 ,, |
| 4340 | 0·035 | 1·00 ,, |

Actual measurement shows that the distance between the centres of neighbouring grains on a photographic film of average goodness lies between $0^{mm}\cdot01$ and $0^{mm}\cdot035$, and a fair average value seems to be $0^{mm}\cdot02$ or $0^{mm}\cdot025$. With the telephoto camera the image of the slit is twice as wide as the actual slit. It is thus seen that, with a slit-width $0^{mm}\cdot025$, the image on the plate involves two grains in its width.

It will be noted that the width of slit is, in the case just dealt with, twice as wide as the diameter of the first diffraction-ring in the star image. It would seem to me to be convenient to introduce the term "tremor-disc." The name more or less explains itself: it is easiest to state what it is intended to convey by reference to a photograph of a star taken with a long exposure. The star-image moves about on the plate in consequence of atmospheric tremor, and produces its effect at each spot on which it rests; the developed image is strongest where the star has most frequently rested; the distribution of density is probably symmetrical about the mean position of the star, and the intensity at different points along a diameter of the resulting tremor-disc is probably fairly well represented by a "law of errors" curve. Apart from the photograph, which shows the summation of the effects, the tremor-disc may be conceived as existing in time, so to speak; and the effect produced in a slit-spectroscope depends on the relation between a certain area of tremor-disc and the area of the slit illumined by it. The tremor-disc is of greater importance, so far as the design of a stellar spectroscope is concerned, than the diffraction-disc, which has generally been considered.

The tremor-disc at Cambridge frequently has a diameter of

8″ or even 10″ ; and on average nights it is probably fully 5″. Assuming that the bright central part is 3″, this would be a disc whose linear diameter is 0·09 mm., and whose area is three times as great as the illumined part of the widest slit which it is thought advisable to use.

The instrument has been named the Bruce Spectroscope, since it is one of the numerous outcomes of Miss Bruce's Grant in Aid of Astronomical Research. A portion of this grant was through Professor E. C. Pickering awarded to Professor Adams for the purchase of an instrument for the Cambridge Observatory ; and it was decided to use it in providing a spectroscope for the 25-inch refractor. As the spectroscope is, in this sense, of American origin, it is a special satisfaction to record that the optical parts were (with the exception of the Dallmeyer telephoto combination above referred to) made in America. They were supplied by Mr. Brashear, of Allegheny, and the excellence of their finish and performance is admirable. The mechanical parts of the instrument were made by the Cambridge Scientific Instrument Company ; and I gladly take this opportunity of saying how much their care in carrying out the somewhat troublesome design, and the ingenuity with which many difficulties were overcome, have contributed to the success of the instrument.

At the present moment I am not quite prepared to express a final opinion on the success of the general design of the instrument, for there are some points on which I wish to have more precise knowledge. I had hoped to have gained that knowledge before presenting this description, but the weather has been so unfavourable—there has not been a single observing night in the past four weeks—that my hopes have been frustrated, and it has seemed better to present the description at once and leave for a later communication some account of the points I have referred to.

Meanwhile it will probably be of interest to give the following particulars with reference to the spectra photographed with the telephoto camera and with a slit-width of $0^{mm}{\cdot}02$.

With an exposure of 7 minutes, the spectrum of *Venus* comes up with excellent clearness.

With an exposure of 10 minutes, the spectrum of *α Lyræ* from D to $H_\gamma$ is over-exposed in some parts.

An exposure of 20 minutes gives the spectrum of *α Aurigæ* at $H_\gamma$ at its best.

An exposure of 30 minutes is enough for *γ Cassiopeiæ*, and with this exposure the doubleness of the bright hydrogen lines, $H_\beta$ and $H_\gamma$ is clearly seen.

An exposure of 40 or 50 minutes is required to give a spectrum showing the green bands in *α Orionis* satisfactorily. With this exposure the spectrum is shown from D to λ 4400.

It should, however, be stated that the width of the spectrum is, in the case of the stars, small—rather less than 1 mm. This small

width is found enough for measurement with the microscope, and I have not as yet made any wider spectra for inspection without the microscope.

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*Expressions for the Elliptic Coordinates of a Moving Point to the Seventh Order of Small Quantities.* By E. J. Stone, M.A., F.R.S., Radcliffe Observer.

The mathematical investigations of the Lunar Theory based upon the variations of the elliptic elements have been carried to the seventh order of small quantities. And this requires for completeness the use of the elliptic coordinates to the same order.

But I have failed to find the complete expressions for these coordinates to the seventh order in any of the books in the Observatory library to which I have referred.

I have, therefore, determined these expressions for my own use. And, as they have been found quite independently, they will serve as a verification of any existing results.

The notation adopted is that of Delaunay's "Théorie de la Lune."

The expressions for $r$, $v$, V, and U agree identically, to the sixth order of the small quantities, with those given by Delaunay on pages 19 and 55–59, vol. i., of the "Théorie de la Lune," and adopted by him in the formation of the general expression of the disturbing function R. But it appears that Delaunay has subsequently allowed for the terms of the seventh order in the expressions for the elliptic coordinates, with the exception of the terms multiplied by $e^7$ and $\gamma^7$ and the coefficients of periodical terms involving the angle $(7l)$; and he must therefore have been in possession of the complete expressions to the seventh order.

$$\begin{aligned}\frac{r}{a} &= 1 + \frac{1}{2}e^2. \\ &+ \cos l \left(-e + \frac{3}{8}e^3 - \frac{5}{192}e^5 + \frac{7}{9216}e^7\right). \\ &+ \cos 2l \left(-\frac{e^2}{2} + \frac{e^4}{3} - \frac{e^6}{16}\right). \\ &+ \cos 3l \left(-\frac{3}{8}e^3 + \frac{45}{128}e^5 - \frac{567}{5120}e^7\right). \\ &+ \cos 4l \left(-\frac{1}{3}e^4 + \frac{2}{5}e^6\right). \\ &+ \cos 5l \left(-\frac{125}{384}e^5 + \frac{4375}{9216}e^7\right). \\ &+ \cos 6l \left(-\frac{27}{80}e^6\right). \\ &+ \cos 7l \left(-\frac{16807}{46080}e^7\right).\end{aligned}$$

$$\left.\begin{array}{l} \nu = g + l. \\ \quad + \sin l \left( + 2e - \frac{e^3}{4} + \frac{5}{96} e^5 + \frac{107}{4608} e^7 \right). \\ \quad + \sin 2l \left( + \frac{5}{4} e^2 - \frac{11}{24} e^4 + \frac{17}{192} e^6 \right). \\ \quad + \sin 3l \left( + \frac{13}{12} e^3 - \frac{43}{64} e^5 + \frac{95}{512} e^7 \right). \\ \quad + \sin 4l \left( + \frac{103}{96} e^4 - \frac{451}{480} e^6 \right). \\ \quad + \sin 5l \left( + \frac{1097}{960} e^5 - \frac{5957}{4608} e^7 \right). \\ \quad + \sin 6l \left( + \frac{1223}{960} e^6 \right). \\ \quad + \sin 7l \left( + \frac{47273}{32256} e^7 \right). \end{array}\right.$$

$$\left.\begin{array}{l} \frac{a}{r} = 1. \\ \quad + \cos l \left( + e - \frac{e^3}{8} + \frac{e^5}{192} - \frac{e^7}{9216} \right). \\ \quad + \cos 2l \left( + e^2 - \frac{e^4}{3} + \frac{e^6}{24} \right). \\ \quad + \cos 3l \left( + \frac{9}{8} e^3 - \frac{81}{128} e^5 + \frac{729}{5120} e^7 \right). \\ \quad + \cos 4l \left( + \frac{4}{3} e^4 - \frac{16}{15} e^6 \right). \\ \quad + \cos 5l \left( + \frac{625}{384} e^5 - \frac{15625}{9216} e^7 \right). \\ \quad + \cos 6l \left( + \frac{81}{40} e^6 \right). \\ \quad + \cos 7l \left( + \frac{117649}{46080} e^7 \right). \end{array}\right.$$

$$\begin{array}{l} V = h + g + l. \\ \quad + \sin l \left( + 2e - \frac{e^3}{4} + \frac{5}{96} e^5 + \frac{107}{4608} e^7 \right). \\ \quad + \sin 2l \left( + \frac{5}{4} e^2 - \frac{11}{24} e^4 + \frac{17}{192} e^6 \right). \\ \quad + \sin 3l \left( + \frac{13}{12} e^3 - \frac{43}{64} e^5 + \frac{95}{512} e^7 \right). \\ \quad + \sin 4l \left( + \frac{103}{96} e^4 - \frac{451}{480} e^6 \right). \\ \quad + \sin 5l \left( + \frac{1097}{960} e^5 - \frac{5957}{4608} e^7 \right). \end{array}$$

$$+\sin 6l\left(+\frac{1223}{960}e^6\right).$$

$$+\sin 7l\left(+\frac{47273}{32256}e^7\right).$$

$$+\sin(2g+2l)\left[-\gamma^2-\gamma^4+4\gamma^2e^2-\gamma^6+4\gamma^4e^2-\frac{55}{16}\gamma^2e^4\right].$$

$$+\sin(2g+3l)\left[-2\gamma^2e-2\gamma^4e+\frac{27}{4}\gamma^2e^3-\frac{207}{32}\gamma^2e^5+\frac{27}{4}\gamma^4e^3-2\gamma^6e\right].$$

$$+\sin(2g+l)\left[+2\gamma^2e+2\gamma^4e-\frac{7}{4}\gamma^2e^3+\frac{5}{96}\gamma^2e^5-\frac{7}{4}\gamma^4e^3+2\gamma^6e\right].$$

$$+\sin(2g+4l)\left[-\frac{13}{4}\gamma^2e^2-\frac{13}{4}\gamma^4e^2+\frac{259}{24}\gamma^2e^4\right].$$

$$+\sin(2g)\left[-\frac{3}{4}\gamma^2e^2-\frac{3}{4}\gamma^4e^2-\frac{1}{8}\gamma^2e^4\right].$$

$$+\sin(2g+5l)\left[-\frac{59}{12}\gamma^2e^3+\frac{3221}{192}\gamma^2e^5-\frac{59}{12}\gamma^4e^3\right].$$

$$+\sin(2g-l)\left[-\frac{1}{12}\gamma^2e^3-\frac{5}{192}\gamma^2e^5-\frac{1}{12}\gamma^4e^3\right].$$

$$+\sin(2g+6l)\left[-\frac{115}{16}\gamma^2e^4\right].$$

$$+\sin(2g-2l)\left[-\frac{1}{24}\gamma^2e^4\right].$$

$$+\sin(2g+7l)\left[-\frac{9893}{960}\gamma^2e^5\right].$$

$$+\sin(2g-3l)\left[-\frac{9}{320}\gamma^2e^5\right].$$

$$+\sin(4g+4l)\left[+\frac{1}{2}\gamma^4+\gamma^6-8\gamma^4e^2\right].$$

$$+\sin(4g+5l)\left[+2\gamma^4e-\frac{85}{4}\gamma^4e^3+4\gamma^6e\right].$$

$$+\sin(4g+3l)\left[-2\gamma^4e+\frac{45}{4}\gamma^4e^3-4\gamma^6e\right].$$

$$+\sin(4g+6l)\left[+\frac{21}{4}\gamma^4e^2\right].$$

$$+\sin(4g+2l)\left[+\frac{11}{4}\gamma^4e^2\right].$$

$$+\sin(4g+7l)\left[+\frac{137}{12}\gamma^4e^3\right].$$

$$+\sin(4g+l)\left[-\frac{17}{12}\gamma^4e^3\right].$$

$$+\sin(6g+6l)\left[-\frac{1}{3}\gamma^6\right].$$

$$+\sin(6g+7l)\left[-2\gamma^6e\right].$$

$$+\sin(6g+5l)\left[+2\gamma^6e\right].$$

$$U = \sin(g+l)\left[2\gamma - 2\gamma e^2 - \frac{1}{4}\gamma^5 + \frac{7}{32}\gamma e^4 - \frac{5}{144}\gamma e^6 + \frac{1}{4}\gamma^5 e^2 + \frac{3}{8}\gamma^7\right].$$

$$\sin(g+2l)\left[2\gamma e - \frac{5}{2}\gamma e^3 - \frac{1}{4}\gamma^5 e + \frac{17}{24}\gamma e^5\right].$$

$$\sin g\left[-2\gamma e + \frac{1}{4}\gamma^5 e\right].$$

$$\sin(g+3l)\left[+\frac{9}{4}\gamma e^2 - \frac{27}{8}\gamma e^4 + \frac{765}{512}\gamma e^6 - \frac{9}{32}\gamma^5 e^2\right].$$

$$\sin(g-l)\left[-\frac{1}{4}\gamma e^2 + \frac{1}{24}\gamma e^4 + \frac{37}{1536}\gamma e^6 + \frac{1}{32}\gamma^5 e^2\right].$$

$$\sin(g+4l)\left[+\frac{8}{3}\gamma e^3 - \frac{14}{3}\gamma e^5\right].$$

$$\sin(g-2l)\left[-\frac{1}{6}\gamma e^3 + \frac{1}{24}\gamma e^5\right].$$

$$\sin(g+5l)\left[+\frac{625}{192}\gamma e^4 - \frac{625}{96}\gamma e^6\right].$$

$$\sin(g-3l)\left[-\frac{9}{64}\gamma e^4 + \frac{9}{160}\gamma e^6\right].$$

$$\sin(g+6l)\left[+\frac{81}{20}\gamma e^5\right].$$

$$\sin(g-4l)\left[-\frac{2}{15}\gamma e^5\right].$$

$$\sin(g+7l)\left[+\frac{117649}{23040}\gamma e^6\right].$$

$$\sin(g-5l)\left[-\frac{625}{4608}\gamma e^6\right].$$

$$\sin(3g+3l)\left[-\frac{1}{3}\gamma^3 - \frac{1}{4}\gamma^5 + 3\gamma^3 e^2 - \frac{405}{64}\gamma^3 e^4 + \frac{9}{4}\gamma^5 e^2 - \frac{3}{8}\gamma^7\right].$$

$$\sin(3g+4l)\left[-\gamma^3 e - \frac{3}{4}\gamma^5 e + \frac{13}{2}\gamma^3 e^3\right].$$

$$\sin(3g+2l)\left[+\gamma^3 e + \frac{3}{4}\gamma^5 e - \frac{11}{4}\gamma^3 e^3\right].$$

$$\sin(3g+5l)\left[-\frac{17}{8}\gamma^3 e^2 + \frac{593}{48}\gamma^3 e^4 - \frac{51}{32}\gamma^5 e^2\right].$$

$$\sin(3g+l)\left[-\frac{7}{8}\gamma^3 e^2 + \frac{31}{48}\gamma^3 e^4 - \frac{21}{32}\gamma^5 e^2\right].$$

$$\sin(3g+6l)\left[-\frac{47}{12}\gamma^3 e^3\right].$$

$$\sin 3g\left[+\frac{1}{6}\gamma^3 e^3\right].$$

$$\sin(3g+7l)\left[-\frac{2567}{384}\gamma^3 e^4\right]$$

$$\sin(3g-l)\left[+\frac{5}{384}\gamma^3 e^4\right].$$

$$\sin(5g+5l)\left[+\frac{3}{20}\gamma^5+\frac{1}{4}\gamma^7-\frac{15}{4}\gamma^5e^2\right].$$

$$\sin(5g+6l)\left[+\frac{3}{4}\gamma^5e\right].$$

$$\sin(5g+4l)\left[-\frac{3}{4}\gamma^5e\right].$$

$$\sin(5g+7l)\left[+\frac{75}{32}\gamma^5e^2\right].$$

$$\sin(5g+3l)\left[+\frac{45}{32}\gamma^5e^2\right].$$

$$\sin(7g+7l)\left[-\frac{5}{56}\gamma^7\right].$$

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*On the Determination of Positions of Stars for the Astrographic Catalogue at the Royal Observatory, Greenwich.* By W. H. M. Christie, M.A., F.R.S., and F. W. Dyson, M.A.

Systematic measurement of the plates taken at the Royal Observatory for the Astrographic Catalogue was commenced in 1894 October. The measures were made with a glass scale in the focal plane of the viewing microscope, and since 1895 January the duplex micrometer has been almost exclusively used. A brief description of the glass scale and of the essential features of the duplex micrometer is given in the report of the Council of the R.A.S. [*Monthly Notices*, vol. lv. p. 206.] It may be mentioned that the plates, whether for the Chart or for the Catalogue, or for other objects, are all numbered consecutively in the order in which they are taken.

The coordinates of both the $6^m$ and $3^m$ images were measured, and the means were taken and used as the star's coordinates on the plate in subsequent reductions. When the images were sensibly circular the mean radius was measured; when elliptical, the greatest and least radii.

*Thirty* overlapping quarter-plates have been connected and compared with one another, all the stars common to the two plates being used. The stars whose places are given in the catalogues of the Astronomische Gesellschaft have been compared with the measured places on *seventy-two* plates. In both cases the linear method of reduction proposed by Professor Turner has been employed.

The chief points considered in this paper are—

1. The arrangement of the measures.
2. Connection of overlapping plates.
   (*a*) Mean discordances in the measures on overlapping plates, and

(*b*) Probable error of the relative constants.
(*c*) Systematic error in the relative constants.

3. Comparison with the Zone Catalogues of the Astronomische Gesellschaft.
   (*a*) Method of forming standard coordinates.
   (*b*) Mean discordances between the measures and the catalogue places, and
   (*c*) Probable errors of the absolute plate constants.
   (*d*) Errors of the catalogues employed.

### 1. *Arrangement of the Measures.*

By a resolution of the Congress the whole sky is to be completely covered by two sets of photographs. Roughly speaking, the corners of one set of plates are at the centres of the other set. In order to make sure of taking the whole of the sky, the plates overlap one another to some extent, so that while every star appears on at least two plates, some may occur on three, four, or five plates. The diagram illustrates the arrangement of these plates, though the inclinations are exaggerated for the sake of clearness. A star near the centre of A would be shown as well on the right-hand bottom corner of B, the left-hand bottom corner of C, and on the top right and left-hand corners respectively of two plates in a lower zone. There seems no object in giving some stars more than twice, while by far the greatest number are given only twice, but it is desirable to place together the measures of the same stars on the two plates. The duplex micrometer lends itself to this object. In the

Diagram I.

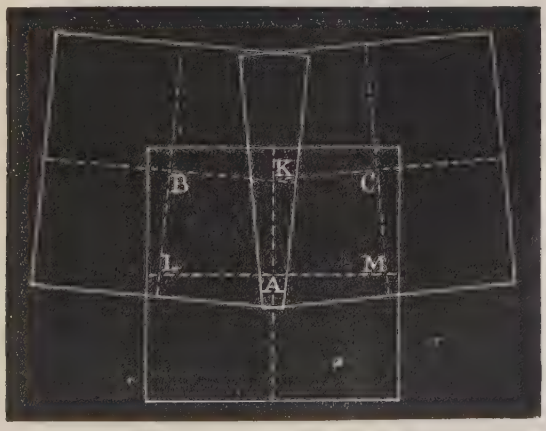



Diagram I., A, B, C are the centres of the three plates; AK, LAM, BL, BK, and CM, CK are the central *réseau* lines;

AK, BL, and CM being the projections of meridians on the respective plates, and LAM, BK, and CK the projections of great circles perpendicular to these meridians. When the two plates A and B are being measured in the duplex micrometer, the same star on the two plates is simultaneously under the two microscopes, and if the area measured is confined to that bounded by the central *réseau* lines of the two plates—that is, the area BLAK—and the same rule is adhered to with each pair of plates measured, then the whole sky will be divided into areas such as BLAK, KAMC, and the position of each star will be measured on two plates, and on two only, and the measures of the same star are automatically brought together.

Diagram II. shows into what portions the sky will be divided. A, B, C, K, L, M, correspond to the same letters in Diagram I. D is the centre of an adjacent plate in the same zone as A, E the centre of a third plate in the same zone as C and B.

Diagram II.

A modification of this method is necessary in what are called the transition zones, *i.e.* consecutive zones in which the number of plates per zone is changed. The same principle may be applied, however, and it is only necessary to substitute some other *réseau* lines instead of the central meridianal ones as the boundaries of the measures. If the same line on A is used when A is measured with B as when A is measured with C, the whole sky will be covered.

The measures are entered in the following form, the plates whose centres are at the smaller declination being placed on the left-hand side of the page :—

Zone +65°.

Plate 2270, R.A. 19h 57m. Plate 2290, R.A. 19h 48m.

| No. | Radii. | $x_1$ | | $y_1$ | | $x_1-x_2$ | $y_1-y_2$ | Radii. | $x_2$ | | $y_2$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18 | 0·5 | 11·936 | 6 | 15·454 | 2 | ... | ... | 1·5 0·5 | 20·550 | 0 | 4·834 | 5 |
| | 0·3 | 6 | 5 | ·385 | 2 | ... | ... | 1·4 0·4 | ·46 | 7 | ·765 | 5 |
| | | 11 9356 | | 15·4185 | | −8·3873 | 10·6184 | | 20 5483 | | 4·7999 | |

After the measures common to these plates follow those common to Plate 2270, R.A. 19h 57m, and Plate 2338, R.A. 20h 6m.

The readings on the glass scale of the two *réseau* lines between which the star is contained are given on the same horizontal line; the measures of the 3m images are placed under those of the 6m images, and the mean includes the correction for runs. The unit for the coordinates $x$ and $y$ is one *réseau*-interval $=5'$, and for the radii 1 div. of glass scale $=0{\cdot}01$ *réseau*-interval $=3''$.

## 2. *Comparison of Plates inter se.*

4. In a paper published in the *Monthly Notices*, 1894 December, the results of a comparison of the measures of stars on four plates were given, the four plates being so arranged that each covered part of the sky covered by two of the others.

Since then the measures on twenty overlapping plates have been compared, the means of the measures of the 6m and 3m exposures being used. For convenience the notation may be again explained.

$x_1$, $y_1$ are the star's measured coordinates on one plate.

$x_{12}$, $y_{12}$, are coordinates obtained from these by a theoretical transformation which would accurately give the star's coordinates on the second plate if the plates had no errors of setting, &c., and such errors as refraction, &c. were all corrected.

$x_2$, $y_2$, are the star's measured coordinates on the second plate.

$a$, $b$, $c$, $d$, $e$, $f$, are constants obtained by the solution of equations of the form

$$x_2 - x_{12} = ax_2 + by_2 + c$$
$$y_2 - y_{12} = dx_2 + ey_2 + f$$

that is to say, by a comparison of all the measures on the two plates.

It is unnecessary to give any details of the arithmetical methods employed to minimise the labour of obtaining $x_{12}$, $y_{12}$, from $x_1$, $y_1$, and the relative constants $a$, $b$, $c$, $d$, $e$, $f$. Practically they are identical with those given by Professor Turner (*Monthly Notices*, Vol. LV. p. 102), the only differences worth mentioning being that another figure has been used throughout the computations, and that the correction for the small square terms was taken from a table instead of from a diagram.

With these constants the corrections $ax + by + c$, $dx + ey + f$ have been computed for several plates, and the residuals

$$x_2 - x_{12} - ax_2 - by_2 - c$$
$$y_2 - y_{12} - dx_2 - cy_2 - f$$

have been formed.

The results obtained are—

| Nos. of Plates. | No. of Stars. | Mean Discordances $x$ Coor. | $y$ Coor. |
|---|---|---|---|
| | | ″ | ″ |
| 1274–443 | 40 | ±·51 | ±·66 |
| 534–444 | 128 | ±·45 | ±·45 |
| 1274–444 | 44 | ±·63 | ±·39 |
| 2290–2270 | 28 | ±·45 | ±·57 |
| 2251–1397 | 34 | ±·33 | ±·33 |
| 2251–2306 | 28 | ±·39 | ±·36 |
| 2251–2290 | 50 | ±·39 | ±·36 |
| Mean | ... | ±·45 | ±·44 |

Thus the mean error of a position on one plate is ±0″·31, giving a probable error ±0″·27.

*The Probable Errors of the Relative Constants* a, b, c, d, e, f.

The values of the constants $a$, $b$, $c$, are obtained by solving equations of the form

$$ax + by + c = \alpha.$$

Instead of solving these equations by least squares, practically as good results are obtained by taking the mean of the stars on the top half, and the mean on the bottom half to determine $b$, and similarly by comparing the means for the right and left halves of the plate to determine $a$.

If there are $n$ stars fairly uniformly distributed over the quarter plate, we have four equations approximating to

$$\left.\begin{aligned} \frac{n}{2}\{c+6a+9b\} &= \alpha_1 \\ \frac{n}{2}\{c+6a+3b\} &= \alpha_2 \\ \frac{n}{2}\{c+3a+6b\} &= \alpha_3 \\ \frac{n}{2}\{c+9a+6b\} &= \alpha_4 \end{aligned}\right\}$$

and

where $$\alpha_1+\alpha_2=\alpha_3+\alpha_4.$$

Let

$\epsilon$ = mean discordance between the measures of one star on the two plates.

Then

$\epsilon \times \sqrt{\frac{n}{2}} \times \cdot 85$ = probable error of right-hand side of the above equations,

and we find

$$\left.\begin{aligned} c+6a+6b &= \frac{\alpha_1+\alpha_2}{n}, \text{ with probable error } \frac{\epsilon}{\sqrt{n}} \times \cdot 85 \\ 6a &= \frac{\alpha_1-\alpha_3}{n} \quad ,, \quad ,, \quad \frac{2\epsilon}{\sqrt{n}} \times \cdot 85 \\ 6b &= \frac{\alpha_1-\alpha_2}{n} \quad ,, \quad ,, \quad \frac{2\epsilon}{\sqrt{n}} \times \cdot 85 \end{aligned}\right\}$$

Therefore the probable errors of $a$, $b$, $c$, are

$$\frac{\epsilon}{3\sqrt{n}} \times \cdot 85, \quad \frac{\epsilon}{3\sqrt{n}} \times \cdot 85, \quad \frac{3\epsilon}{\sqrt{n}} \times \cdot 85$$

respectively.

Taking

$$\text{int.}$$
$$n = 49, \text{ and } \epsilon = \pm 0^{\circ}\cdot 0015 = \pm 0''\cdot 45$$

these give probable errors

for $a$ and $b$ $\pm \cdot 00006$, and
for $c$ $\pm 0''\cdot 16$.

These are based on the supposition that the stars are uniformly distributed about the centre of the quarter plate. If this is not the case, these errors will be larger. From actual computation the errors of the relative constants have been found to be as follows :—

| Nos. of Plates. | Probable Errors of relative constants. *a.* | *b.* | *c.* | *d.* | *e.* | *f.* |
|---|---|---|---|---|---|---|
| | | | ″ | | | ″ |
| 1274–443 | ·00008 | ·00006 | 0·16 | ·00011 | ·00007 | 0·21 |
| 534–444 | ·00004 | ·00007 | ·15 | ·00004 | ·00007 | ·15 |
| 1274–444 | ·00008 | ·00010 | ·21 | ·00007 | ·00009 | ·13 |
| 2290–2270 | ·00010 | ·00010 | ·28 | ·00011 | ·00011 | ·34 |
| 2251–1397 | ·00006 | ·00006 | ·18 | ·00006 | ·00006 | ·18 |
| 2251–2306 | ·00006 | ·00008 | ·21 | ·00007 | ·00009 | ·23 |
| 2251–2290 | ·00004 | ·00006 | ·23 | ·00004 | ·00006 | ·21 |

Also in the plates discussed in the *Monthly Notices* 1894 December, p. 62, where the values of the relative constants were found from two independent sets of measures, the probable error of $a$, $b$, $d$, $e$, is seen to be about ·00005, while the differences of $c$ or $f$ from the two sets of measures are

″·60, ″·36, ″·18, ″·78, ″·09, ″·33, ″·84, ″·06,

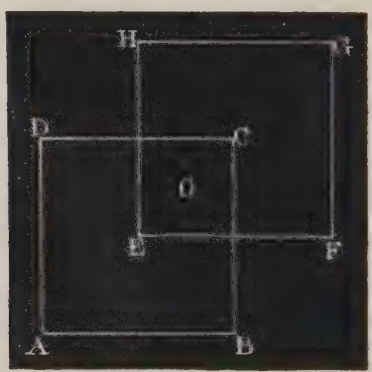
″·15, ″·12, ″·63, ″·36, ″·24, ″·45, ″·06, ″·69.

The mean of these is ″·38, giving a probable error of about ″·2 for a single determination of $c$ or $f$.

We are, therefore, fairly safe in saying that with about fifty stars to a quarter plate the probable error of $a$, $b$, $d$, $e$, is about ·00007, and of $c$ and $f$ about ″·2.

The probable error of the correction $ax_2+by_2+c$, when $x$, $y$ is within the quarter plate, is, in the theoretical case above discussed, between ″·05 and ″·16, or on the average about ″·10.

It seems remarkable at first sight that with fifty stars on a plate, and the probable error of a single measure =″·27, the probable error of $c$ or $f$ should be as large as ″·16, but it is evident geometrically (see diagram below) that while the position of the centre of one quarter plate with respect to that of the other is well determined (that is, points on the two plates near O), the position of the centre of one plate (C) with respect to the centre of the other (E) is, comparatively speaking, badly determined, and the position of G with respect to E is still more uncertain.



The values of the relative constants by which a plate is connected with an overlapping plate are given for thirty plates in the following table.

*Values of the Relative Constants connecting 30 Overlapping Plates.*

| Zone. | Nos. of Plates. | No. of Stars. | *a* | *b* | *c* | *d* | *e* | *f* | *a*−*e* | *b*+*d* |
|---|---|---|---|---|---|---|---|---|---|---|
| 66°–65° | 1274–443 | 40 | +·00008 | −·00712 | −·0273 | +·00713 | +·00002 | +·0666 | +·00006 | +·00001 |
| | 1274–444 | 56 | +·00034 | −·00542 | +·0421 | +·00557 | +·00021 | −·0056 | +·00013 | +·00013 |
| | 534–444 | 128 | +·00011 | −·00249 | +·0309 | +·00266 | +·00008 | −·0305 | +·00003 | +·00017 |
| | 534–1236 | 72 | +·00026 | −·00154 | +·0253 | +·00188 | −·00016 | −·0015 | +·00042 | +·00034 |
| | 426–1236 | 68 | −·00010 | +·00035 | −·0131 | −·00025 | −·00002 | +·1975 | −·00008 | +·00010 |
| | 426–2290 | 48 | −·00003 | +·00167 | −·0010 | −·00154 | −·00020 | +·2958 | +·00017 | +·00013 |
| | 2270–2290 | 28 | −·00035 | −·00017 | −·0741 | +·00042 | +·00013 | −·0570 | −·00048 | +·00025 |
| | 2270–2238 | 44 | +·00002 | −·00054 | −·1026 | +·00026 | −·00015 | +·0225 | +·00017 | −·00028 |
| | 2280–2279 | 62 | −·00008 | −·00071 | +·0174 | +·00054 | +·00007 | +·0378 | −·00015 | −·00017 |
| | 2280–2308 | 76 | −·00001 | −·00031 | −·0640 | +·00014 | +·00001 | +·0843 | −·00002 | −·00017 |
| | 535–2308 | 74 | −·00014 | −·00033 | −·0107 | +·00040 | −·00005 | +·0011 | −·00009 | +·00007 |
| 66°–67° | 2288–443 | 28 | −·00019 | −·00312 | −·0223 | +·00314 | −·00019 | −·1331 | ·00000 | +·00002 |
| | 2288–444 | 114 | +·00015 | −·00176 | +·0080 | +·00178 | +·00009 | −·1169 | +·00006 | +·00002 |
| | 2289–1236 | 76 | −·00005 | −·00131 | +·0975 | +·00112 | −·00009 | −·0549 | +·00003 | −·00019 |
| | 2251–2290 | 50 | −·00010 | +·00033 | +·0879 | −·00031 | −·00013 | +·0557 | −·00003 | +·00002 |
| | 1416–2338 | 64 | −·00020 | −·00042 | +·0120 | +·00028 | +·00007 | −·0122 | −·00027 | −·00002 |

| Zone. | Nos. of Plates. | No. of Stars. | *a* | *b* | *c* | *d* | *e* | *f* | *a*−*e* | *b*+*d* |
|---|---|---|---|---|---|---|---|---|---|---|
| 68°–67° | 2288–2227 | 52 | + ·00003 | − ·00038 | − ·0618 | + ·00023 | − ·00011 | − ·0811 | + ·00014 | − ·00015 |
| | 2289–2227 | 58 | − ·00009 | − ·00039 | + ·0204 | + ·00051 | − ·00013 | − ·0548 | + ·00004 | + ·00012 |
| | 2289–1397 | 60 | + ·00014 | + ·00068 | + ·0129 | − ·00057 | + ·00008 | + ·0244 | + ·00006 | + ·00011 |
| | 2251–1397 | 34 | − ·00019 | + ·00097 | − ·0420 | − ·00068 | + ·00003 | + ·0112 | − ·00016 | + ·00029 |
| | 2251–2306 | 28 | − ·00004 | − ·00087 | + ·0798 | + ·00086 | − ·00013 | + ·1100 | + ·00009 | − ·00001 |
| | 1416–2306 | 46 | − ·00024 | − ·00157 | + ·0378 | + ·00161 | − ·00008 | + ·0032 | − ·00016 | + ·00004 |
| 68°–69° | 1323–2227 | 96 | − ·00023 | + ·00200 | − ·0139 | − ·00202 | − ·00017 | − ·0104 | − ·00006 | − ·00002 |
| | 1323–1397 | 90 | − ·00010 | + ·00318 | + ·0075 | − ·00307 | − ·00016 | + ·0773 | + ·00006 | + ·00011 |
| | 2291–1397 | 46 | − ·00014 | + ·00177 | + ·0170 | − ·00182 | − ·00014 | + ·0134 | 00000 | − ·00005 |
| | 2291–2306 | 48 | + ·00010 | + ·00008 | + ·0911 | − ·00002 | − ·00012 | + ·1087 | + ·00022 | + ·00006 |
| 67°–68° | 2056–2057 | 50 | − ·00030 | − ·00165 | − ·0236 | + ·00174 | + ·00000 | + ·1246 | − ·00030 | + ·00009 |
| | 2056–2058 | 52 | + ·00027 | − ·00024 | + ·0266 | + ·00037 | − ·00006 | + ·0119 | + ·00031 | + ·00013 |
| 68°–69° | 2057–2059 | 43 | + ·00025 | + ·00116 | + ·0220 | − ·00101 | + ·00006 | − ·1016 | + ·00019 | + ·00015 |
| | 2058–2059 | 61 | − ·00008 | − ·00036 | − ·0260 | + ·00040 | − ·00003 | + ·0284 | − ·00005 | + ·00004 |
| | Mean Discordance from zero | ... | ± ·00015 | | | | ± ·00019 | | ± ·00013 | ± ·00012 |

$c$ and $f$, which are expressed in terms of the *réseau*-interval (int. $0{\cdot}1 = 30''$), arise from errors of setting of the plates.

Difference of orientation error of the two plates would be given by $b$ and $d$, and for this error alone the relation $b+d=0$ should hold.

A difference of scale on the two plates would be given by $a$ and $e$, and for this error alone the relation $a-e=0$ should hold. A difference in the corrections for refraction and aberration on adjacent plates would at most be 1 or 2 units in the fifth place in $a$, $b$, $d$, and $e$, and may here be treated as insensible.

The average value of $a$ on these thirty plates is $\pm{\cdot}00015$, of $e \pm{\cdot}00010$, of $a-e \pm{\cdot}00013$. and of $b+d \pm{\cdot}00012$. Taking the probable error of a determination of $a$, $b$, $d$, $e$ as $\pm{\cdot}00007$, that of $a-e$ and $b+d$ would be $\pm{\cdot}00010$, and the mean error (i.e. mean of the errors irrespective of sign) would be $\pm{\cdot}00012$, which agrees exactly with the value of the mean discordance found above. This table seems, therefore, to show that the differences of $a-e$ and $b+d$ from zero are accidental.

To test further the accidental nature of the differences $a-e$ and $b+d$, the plates showing the largest values of these quantities in the above table (Plates 2290 and 2270) were connected on the two hypotheses :—(1) that the differences $a-e$ and $b+d$ were real ; (2) that they were accidental, and that

$$a = e = \frac{a+e}{2} \text{ and } b = -d = \frac{b-d}{2}$$

and the discordances were formed. The mean discordance is slightly increased, there being in the second case only four quantities at disposal instead of six, but so slightly that the introduction of two arbitrary corrections for which no physical reason is given does not seem to be justified. The discordances found by the two methods are given in the following table.

*Comparison of Plates* 2290 *and* 2270 *on two Hypotheses.*

| Coordinates on Plate 2270. | | Discordances in $x$ Coor. | | Discordances in $y$ Coor. | |
|---|---|---|---|---|---|
| | | (1) $a, e, b, d$ independ. | (2) $a=e$ $b=-d$ | (1) $a, e, b, d$ independ. | (2) $a=e$ $b=-d$ |
| $x$ | $y$ | | | | |
| 1·90 | 21·91 | +·0005 | +·0019 | +·0000 | −·0005 |
| 1·77 | 16·43 | + 18 | + 27 | − 30 | − 49 |
| 3·35 | 22·37 | + 5 | + 16 | + 22 | + 21 |
| 3·46 | 22·21 | − 2 | + 17 | − 26 | − 27 |
| 4·17 | 16·68 | + 10 | + 10 | − 6 | − 16 |
| 4·19 | 20·90 | − 1 | + 6 | + 15 | + 11 |
| 4·13 | 21·38 | − 10 | − 3 | + 1 | − 6 |
| 5·65 | 17·44 | − 9 | − 8 | + 60 | + 49 |
| 5·63 | 20·02 | + 19 | + 21 | + 17 | + 22 |
| 6·49 | 23·38 | − 30 | − 27 | + 8 | + 13 |
| 6·16 | 21·97 | + 24 | + 27 | − 34 | − 33 |
| 7·07 | 16·39 | + 23 | + 14 | + 3 | − 8 |
| 7·56 | 17·29 | − 37 | − 45 | − 24 | − 33 |
| 7·65 | 17·34 | − 24 | − 20 | − 5 | − 15 |
| 7·96 | 23·45 | + 27 | + 26 | + 4 | + 22 |
| 8·93 | 26·33 | + 3 | + 5 | − 26 | − 11 |
| 8·90 | 17·00 | + 15 | + 4 | − 35 | − 43 |
| 9·15 | 16·71 | + 3 | + 2 | − 7 | − 15 |
| 9·54 | 19·83 | − 11 | − 18 | − 38 | − 38 |
| 10·32 | 22·52 | − 3 | − 10 | + 28 | + 34 |
| 10·04 | 20·32 | − 6 | − 27 | + 23 | + 25 |
| 10·06 | 18 50 | + 16 | + 5 | + 8 | + 5 |
| 10·82 | 16·66 | + 31 | + 13 | − 13 | − 19 |
| 11·04 | 20·66 | − 28 | − 40 | + 3 | + 6 |
| 11·41 | 20·33 | + 3 | + 10 | − 13 | + 17 |
| 11·15 | 23 66 | − 19 | − 27 | + 12 | + 25 |
| 11·98 | 26·29 | + 8 | + 1 | + 43 | + 62 |
| 13·45 | 25·91 | − 19 | − 30 | − 16 | + 1 |
| Mean discordance ... | | ±·0015 | ±·0017 | ±·0019 | ±·0023 |

*Systematic Error in the Determination of* a.

In the two following tables the relative constants $a$, $e$, and $b+d$ are given, according as they refer respectively to plates in which a S.E. and N.W. quarter correspond or a S.W. and N.E. quarter :—

*Relative Constants found by transforming from S.E. to N.W.*

| Zones. | Nos. of Plates. | | $a$ | $e$ | $b+d$ |
|---|---|---|---|---|---|
| 66°–65° | 443–1274 | | −·00008 | −·00002 | −·00001 |
| | 444–534 | | −·00011 | −·00008 | −·00017 |
| | 1236–426 | | +·00010 | +·00002 | −·00010 |
| | 2290–2270 | | +·00035 | −·00013 | −·00025 |
| | 2279–2280 | | +·00008 | −·00007 | +·00017 |
| | 2308–535 | | +·00014 | +·00005 | +·00007 |
| | | Means ... | +·00008 | −·00005 | −·00005 |
| 68°–67° | 2227–2289 | | +·00009 | +·00013 | −·00012 |
| | 1397–2251 | | +·00019 | −·00003 | −·00029 |
| | 2306–1416 | | +·00024 | +·00008 | −·00004 |
| | | Means ... | +·00017 | +·00006 | −·00015 |
| 69°–68° | 1323–1397 | | −·00010 | −·00016 | −·00001 |
| | 2291–2306 | | +·00010 | −·00012 | +·00006 |
| | | Means ... | ·00000 | −·00014 | +·00002 |
| | 2056–2058 | | +·00027 | +·00066 | +·00013 |
| | 2057–2059 | | +·00025 | +·00006 | +·00015 |

*Relative Constants found by transforming from S.W. to N.E.*

| Zones. | Nos. of Plates. | | $a$ | $e$ | $b+d$ |
|---|---|---|---|---|---|
| 66°–65° | 444–1274 | | −·00034 | −·00021 | −·00013 |
| | 1236–534 | | −·00026 | +·00016 | −·00034 |
| | 2290–426 | | +·00003 | +·00020 | −·00013 |
| | 2338–2270 | | −·00002 | +·00015 | +·00028 |
| | 2308–2280 | | +·00001 | −·00001 | +·00017 |
| | | Means ... | −·00012 | +·00006 | −·00003 |
| 68°–67° | 2227–2288 | | −·00003 | +·00011 | +·00015 |
| | 1397–2289 | | −·00014 | −·00008 | −·00011 |
| | 2306–2251 | | +·00004 | +·00013 | +·00001 |
| | | Means ... | −·00004 | +·00005 | +·00002 |

| | | | | |
|---|---|---|---|---|
| 69°–68° | 1323–2227 | −·00023 | −·00017 | −·00002 |
| | 2291–1397 | −·00014 | −·00014 | −·00005 |
| | Means ... | −·00018 | −·00015 | −·00003 |
| | 2056–2057 | −·00030 | 00000 | +·00009 |
| | 2058–2059 | −·00008 | −·00003 | +·00004 |

The values of $a$ in the first table are nearly all positive, while those in the second are nearly all negative. This systematic error is shown more distinctly if an overlapping plate is used to connect two plates in the same zone. We thus obtain the following table :—

| Zone. | Nos. of Plates. | Difference of $a$. | Means. |
|---|---|---|---|
| 65° | 1274–534 | +·00023 | +·00026 |
| | 534–426 | +·00036 | |
| | 426–2270 | +·00032 | |
| | 2280–535 | +·00013 | |
| 66° | 443–444 | +·00026 | +·00019 |
| | | +·00034 | |
| | 444–1236 | +·00015 | |
| | 1236–2290 | +·00007 | |
| | 2290–2238 | +·00037 | |
| | 2279–2308 | +·00007 | |
| 67° | 2288–2289 | +·00012 | +·00019 |
| | 2289–2251 | +·00024 | |
| | 2251–1416 | +·00020 | |
| 68° | 2136–2227 | +·00039 | +·00029 |
| | 2227–1397 | +·00023 | |
| | | +·00013 | |
| | 1397–2305 | +·00006 | |
| | | +·00024 | |
| | 2058–2057 | +·00045 | |
| 69° | 1323–2291 | +·00004 | +·00004 |

The mean of these differences is +·00021. The explanation of this systematic error has not been investigated. It may perhaps be due to a systematic difference in division errors of the *réseau*, or in optical distortion between the east and west halves of the plate. Its existence, however, shows that it would be impossible

to step along a zone connecting one plate with another by means of intermediary overlapping plates without introducing a large and uncertain correction for this unexplained error, which is cumulative in its effect.

3. *Comparison of the Measured Coordinates of the Stars with the Places given in the Catalogues of the Astronomische Gesellschaft.*

The places given in the Helsingfors-Gotha (60°–65°) and Christiania (65°–70°) Catalogues were brought up to the epoch 1900·0. The standard coordinates $\xi$, $\eta$ are obtained from the Right Ascensions and North Polar distances by the formulæ

$$\xi = \tan(\alpha - A) \cdot \sin q \cdot \sec(P - q) \quad . \quad (1)$$
$$\eta = \tan(P - q) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

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where $\tan q = \tan p \cdot \cos(\alpha - A)$ . . . . . (3)

To avoid the use of tables of logarithmic sines and cosines computed for every second of arc, to save the conversion of time into arc, and generally to diminish the labour of computation, these formulæ were further transformed. (See *Observatory*, vol. XVIII. pp. 328, 329, 351–355.)

From the third of the above formulæ

$$q = p + \frac{\cos(\alpha - A) - 1}{\cos(\alpha - A) + 1} \sin 2p + \tfrac{1}{3} \cdot \left(\frac{\cos(\alpha - A) - 1}{\cos(\alpha - A) + 1}\right)^2 \sin 4p + \&c. \quad . \quad . \quad . \quad (4)$$

Using declination ($\delta$) instead of north polar distance ($p$) and putting D for the declination of the centre of the plate, we have from (2) and (4)

$$\tan^{-1}\eta = \delta - D + \tan^2 \frac{\alpha - A}{2} \sin 2\delta + \&c.$$

Therefore

$$\eta = \delta - D + \tan^2 \frac{\alpha - A}{2} \sin 2\delta + \&c. + (\eta - \tan^{-1}\eta) \quad . \quad . \quad . \quad . \quad (5)$$

Again, the above formulæ give

$$\xi = (\sin P - \eta \cos P) \cdot \tan(\alpha - A),$$

$\xi$ and $\eta$ being supposed expressed in circular measure, or

$$\xi = \left(\frac{2160}{\pi} \tan P - \eta\right) \cdot \cos P \cdot \tan(\alpha - A) \quad . \quad . \quad . \quad . \quad . \quad (6)$$

when $\xi$ and $\eta$ are expressed in *réseau* intervals (1 *réseau* interval $= 5'$).

From (6) we obtain

$$\log \xi = \log\left\{\left(\frac{2160}{\pi} \tan P - \eta\right) \cdot \cos P\right\} + \log(\alpha - A) + \log \frac{\tan(\alpha - A)}{(\alpha - A)}$$

($\alpha - A$ being expressed in circular measure).

Now

$$\log \frac{\tan(\alpha-A)}{\alpha-A} = \log\left[1+\frac{(\alpha-A)^2}{3}\right]$$

and

$$\log \sec(\alpha-A) = \log\left[1+\frac{(\alpha-A)^2}{2}\right]$$

Therefore

$$\log \frac{\tan(\alpha-A)}{\alpha-A} = \tfrac{2}{3}\log\sec(\alpha-A).$$

Thus we obtain (when $\alpha - A$ is expressed in seconds of time)

$$\log\xi = \log(\alpha-A) + \log\left\{\left(\frac{2160}{\pi}\tan P-\eta\right).\cos P.\sin 15''\right\} + \tfrac{2}{3}\log\sec(\alpha-A) \quad . \quad . \quad . \quad . \quad (7)$$

and formula (5) becomes

$$\eta = \delta - D + \frac{2160}{\pi}\tan^2\frac{\alpha-A}{2}.\sin 2\delta + \frac{2160}{\pi}(\eta-\tan^{-1}\eta) \quad . \quad . \quad . \quad (8)$$

These formulæ give $\xi$ and $\eta$ expressed in *réseau* intervals, the term $\delta - D$, being converted from arc to these units, by means of a small table similar to the table used for converting time into arc.

Tables are formed to give

| | | |
|---|---|---|
| $\delta - D$ in *réseau* intervals . . . . . | arg $(\delta - D)$ . . . . . | Table IV. |
| $\frac{2160}{\pi}\tan^2\frac{\alpha-A}{2}$ and $\frac{2}{3}\log\sec(\alpha-A)$ . . . | arg $(\alpha-A)$ {in seconds of time.} | Table III. |
| $\sin 2\delta$ . . . . . | arg $\delta$ . . . . . | Table II. |
| $\frac{2160}{\pi}(\eta-\tan^{-1}\eta)$ . . . . . | arg $\eta$ . . . . . | Table V. |
| $\log\left\{\left(\frac{2160}{\pi}\tan P-\eta\right)\cos P.\sin 15''\right\}$ | arg $\eta$ . . . . . | Table I. |

All the tables except Table I. are available for all zones; Tables IV. and V. are very small; and they are all very quickly computed from ordinary trigonometrical tables.

As the numbering of the *réseau* lines is such that the central line is called 14, the tables have been computed in accordance with this notation. The multiplication of $\frac{2160}{\pi}\tan^2\frac{\alpha-A}{2}$ and $\sin 2\delta$ is performed by use of Crelle's tables. Log $(\alpha - A)$ is obtained from ordinary logarithm tables without any interpolation being necessary. The numerical work is carried to four places of decimals (the unit being 5′) so that the last figure ·0001 is equal to 0″·03.

The following is the form employed in the computation :—

| | |
|---|---|
| $\alpha$ = R.A. of star for 1900·0 | $\delta$ — Decl. of star for 1900·0 |
| A = R.A. of centre for 1900·0 | D = Decl. of centre for 1900·0 |
| $\alpha - A$ | Table IV. Arg. $\delta$ |
| Log ($\alpha - A$) | Table II. } Product |
| Table III. (1) arg ($\alpha - A$) | Table III. (2) } Table V. |
| Table I. arg $\eta$ | $\eta$ = Sum |
| Sum | |
| Corr. No. | |
| Corr. No. + 14 = $\xi$ | |

The standard coordinates thus found are compared with the measures, and equations

$$\left.\begin{aligned} ax + by + c &= \xi - x \\ dx + ey + f &= \eta - y \end{aligned}\right\}$$

written down for each star on the plate considered which is contained in the Catalogue. The values of the absolute constants $a$, $b$, $c$, $d$, $e$, $f$ are deduced in the same way as in the case of the relative constants. These being determined, the "standard coordinates" of a star whose measured coordinates are $x$ and $y$ are

$$x + ax + by + c$$
$$y + dx + ey + f.$$

These absolute constants have been determined for 72 plates in the zones 65°, 66°, and 67°, and the corrections applied to those stars which are given in the Catalogues. The standard coordinates $\xi$, $\eta$ thus found are compared with those deduced from the Catalogue, which may now be called $\xi_0$, $\eta_0$. The following table of these constants $a$, $b$, $c$, &c., for 10 plates in zone 66° is given as a specimen.

*Absolute Plate Constants. Zone 66°.*

| No. of Plate. | No. of Stars. | $a$ | $b$ | $c$ | $d$ | $e$ | $f$ | $a-e$ | $b+d$ |
|---|---|---|---|---|---|---|---|---|---|
| 2521 | 14 | −·00062 | +·00090 | −·0177 | −·00098 | −·00088 | +·1138 | +·00026 | −·00008 |
| 940 | 18 | −·00083 | +·00058 | −·1635 | −·00095 | −·00062 | +·0856 | −·00021 | −·00037 |
| 941 | 12 | −·00027 | +·00067 | −·1671 | −·00069 | −·00071 | +·1064 | +·00044 | −·00002 |
| 942 | 19 | −·00060 | +·00080 | −·0121 | −·00060 | −·00090 | +·1028 | +·00030 | +·00020 |
| 2526 | 17 | −·00082 | +·00351 | −·0404 | −·00380 | −·00076 | +·1856 | −·00006 | −·00029 |
| 2537 | 17 | −·00069 | +·00081 | −·0279 | −·00083 | −·00071 | +·1088 | +·00002 | −·00001 |
| 962 | 21 | −·00075 | +·00055 | −·1755 | −·00042 | −·00051 | +·0838 | −·00024 | +·00013 |
| 2557 | 22 | −·00072 | +·00052 | −·0536 | −·00052 | −·00046 | +·1014 | −·00026 | ·00000 |
| 2593 | 21 | −·00069 | +·00061 | −·0235 | −·00072 | −·00078 | +·1145 | +·00009 | −·00011 |
| 2559 | 23 | −·00089 | +·00122 | −·0464 | −·00139 | −·00054 | +·1197 | −·000035 | −·00017 |

The average values of the discordances $\xi-\xi_0$, $\eta-\eta_0$ are given below for 24 plates, with the number of Catalogue stars on each plate.

| No. of Plate. | Number of Stars. | Mean discordance. $\xi-\xi_0$ | $\eta-\eta_0$ | No. of Plate. | Number of Stars. | Mean discordance. $\xi-\xi_0$ | $\eta-\eta_0$ |
|---|---|---|---|---|---|---|---|
| | | ″ | ″ | | | ″ | ″ |
| 1274 | 31 | ±0.75 | ±0.81 | 2521 | 14 | ±0.96 | ±0.93 |
| 534 | 40 | ±0.51 | ±0.90 | 940 | 18 | ±0.73 | ±0.93 |
| 2288 | 35 | ±0.63 | ±0.99 | 941 | 12 | ±0.77 | ±0.63 |
| 1323 | 23 | ±0.57 | ±0.93 | 942 | 19 | ±0.72 | ±0.90 |
| 443 | 32 | ±0.63 | ±0.69 | 2526 | 17 | ±0.78 | ±0.96 |
| 444 | 46 | ±0.51 | ±0.69 | 2537 | 17 | ±1.12 | ±0.56 |
| 2251 | 34 | ±0.68 | ±0.99 | 962 | 21 | ±1.05 | ±0.88 |
| 331*a* | 30 | ±0.96 | ±0.99 | 2557 | 22 | ±0.93 | ±1.02 |
| 2522 | 12 | ±0.77 | ±1.19 | 2593 | 21 | ±0.75 | ±0.81 |
| 336 | 20 | ±0.72 | ±0.78 | 2559 | 23 | ±1.11 | ±0.81 |
| 2022 | 28 | ±0.96 | ±0.80 | 2560 | 30 | ±0.54 | ±0.81 |
| 345 | 24 | ±0.62 | ±0.72 | 2654 | 26 | ±0.96 | ±0.99 |

Thus the average discordances for $\xi-\xi_0$ and $\eta-\eta_0$ are ±0″.76 and ±0″.86, and the probable errors of these differences ±0″.65 and ±0″.71.

The probable errors of the absolute plate constants *a*, *b*, *c*, *d*, *e*, *f*, have been deduced in a few cases with the following results:—

| No. of Plate. | No. of Stars. | Probable Error of *a* | *b* | *c* | *d* | *e* | *f* |
|---|---|---|---|---|---|---|---|
| 331*a* | 30 | ±·00007 | ±·00011 | ±0″.19 | ±·00011 | ±·00007 | ±0″.18 |
| 2522 | 12 | ±·00008 | ±·00010 | ±0.30 | ±·00006 | ±·00013 | ±0″.21 |
| 336 | 20 | ±·00005 | ±·00008 | ±0″.14 | ±·00007 | ±·00007 | ±0″.16 |
| 443 | 32 | ±·00008 | ±·00007 | ±0″.14 | ±·00006 | ±·00009 | ±0″.15 |
| 2251 | 34 | ±·00005 | ±·00006 | ±0″.12 | ±·00007 | ±·00008 | ±0″.15 |
| 1274 | 31 | ±·00010 | ±·00009 | ±0″.11 | ±·00009 | ±·00011 | ±0″.14 |
| 2521 | 14 | ±·00014 | ±·00015 | ±0″.28 | ±·00014 | ±·00015 | ±0″.27 |
| 940 | 18 | ±·00018 | ±·00017 | ±0″.18 | ±·00010 | ±·00019 | ±0″.24 |
| 941 | 12 | ±·00007 | ±·00006 | ±0″.13 | ±·00008 | ±·00007 | ±0″.17 |
| 942 | 19 | ±·00009 | ±·00009 | ±0″.18 | ±·00011 | ±·00011 | ±0″.22 |
| 2526 | 17 | ±·00012 | ±·00012 | ±0″.16 | ±·00014 | ±·00014 | ±0″.20 |
| Mean | | ±·00009 | ±·00009 | ±0″.18 | ±·00010 | ±·00010 | ±0″.19 |

We may take the probable error of the constants *a*, *b*, *d*, *e* as about ±·00010, and the mean error as ±·00012.

The constants *a*, *b*, *c*, *d*, *e*, *f*, thus determined by direct comparison of the plates and the Catalogue, contain the corrections

for refraction, aberration, orientation of the plate and value of the scale. In zones 65°, 66°, and 67°, the refraction produces −·00028 in $a$ and −·00030 in $e$, and the variations from these are less than ·00001 when the plates are taken within an hour of the meridian. The effect of refraction on $b$ and $d$ is at most one or two units in the fifth place. The correction for aberration is the same in $a$ and $e$, and, roughly speaking, may vary from +·00003 to −·00005.

When the constants are corrected for aberration, we obtain the following values for $\frac{a+e}{2}$ :—

| | | | | |
|---|---|---|---|---|
| −·00062 | from 11 | plates | in zone | 65° |
| −·00072 | „ 11 | „ | „ | 65 |
| −·00066 | „ 10 | „ | „ | 65 |
| −·00064 | „ 12 | „ | „ | 66 |
| −·00072 | „ 11 | „ | „ | 66 |

The mean of these is −·00067 ; adding −·00029 for refraction, we find the scale correction = −·00096.

The following table exhibits the value of $\frac{a+e}{2}$ (after correction for aberration) on plates taken on the same nights, together with the temperature of the tube :—

| No. of Plate. | When taken. | Temp. of Tube. | $\frac{a+e}{2}$ | Mean value for the night. |
|---|---|---|---|---|
| 861 | 1893 Mar. 17 | 41°·0 | −·00056 | |
| 862 | „ | „ | −·00048 | −·00063 |
| 863 | „ | „ | −·00084 | |
| 940 | 1893 Mar. 29 | 48·3 | −·00067 | |
| 941 | „ | 47·6 | −·00045 | −·00061 |
| 942 | „ | „ | −·00071 | |
| 2521 | 1895 Apr. 10 | 54·0 | −·00070 | |
| 2522 | „ | 53·5 | −·00063 | |
| 2524 | „ | 53·0 | −·00081 | −·00074 |
| 2525 | „ | „ | −·00080 | |
| 2526 | „ | „ | −·00075 | |
| 2554 | 1895 Apr. 23 | 50·0 | −·00057 | |
| 2555 | „ | 49·7 | −·00065 | |
| 2557 | „ | 49·1 | −·00058 | −·00063 |
| 2559 | , | 49·0 | −·00069 | |
| 2560 | „ | „ | −·00067 | |

| | | | | |
|---|---|---|---|---|
| 2568 | 1895 Apr. 24 | 51·0 | −·00046 | |
| 2569 | ,, | 50·0 | −·00068 | −·00056 |
| 2570 | ,, | 50·0 | −·00055 | |
| 2044 | 1894 May 17 | 53·8 | −·00097 | |
| 2046 | ,, | 52·9 | −·00065 | −·00069 |
| 2048 | ,, | 51·3 | −·00044 | |

Examination of this table, as far as it goes, shows that the change in $\frac{a+e}{2}$ is due to accidental errors in the measures and assumed places of the stars, and not to real changes in the scale of the plate.

The following table gives the average values of the discordances of $a$, $e$, and $\frac{a+e}{2}$ (corrected for aberration) from the mean value, and of $a-e$ and $b+d$ from zero :—

| Zone. | Number of Plates. | Discordances from Mean. | | | Discordances from Zero. | |
|---|---|---|---|---|---|---|
| | | $a$ | $e$ | $\frac{a+e}{2}$ | $a-e$ | $b+d$ |
| 65° | 11 | ±·000130 | ±·000189 | ±·000127 | ±·000212 | +·000262 |
| 65 | 11 | ±·000164 | ±·000183 | ±·000105 | ±·000198 | ±·000261 |
| 65 | 10 | ±·000114 | ±·000097 | ±·000093 | ±·000153 | ±·000168 |
| 66 | 12 | ±·000123 | ±·000100 | ±·000073 | ±·000210 | ±·000163 |
| 67 | 11 | ±·000163 | ±·000136 | ±·000143 | ±·000149 | ±·000271 |
| Mean | 55 | ±·000139 | ±·000141 | ±·000108 | ±·000184 | ±·000225 |

There does not seem to be any physical reason why $a-e$ and $b+d$ should differ from zero, at any rate by more than one or two figures in the fifth place. Remembering this, and comparing the above table with the mean error previously found for $a$, $e$, $b$, and $d$—viz. ±·00012, which would give ±·00017 as the mean error of $a-e$, or $b+d$, we conclude that these discordances are mainly due to accidental errors in the measured coordinates of the stars and of the assumed right ascensions and declinations. It therefore seems that by adopting a constant value for the scale, and assuming that the conditions $a-e=0$ and $b+d=0$ hold, better values of the plate constants will be obtained. When the correction for aberration is not separately applied, the values

$$a=e=-\cdot00070$$

and

$$b=-d=\frac{b-d}{2}$$

differ but slightly from the true values, and it is proposed to adopt these values in the formation of residuals from which final

corrections to the plate constants may be deduced. The values adopted for $a$ and $e$ include a mean correction of $-\cdot00029$ for refraction, and the variations in the corrections for refraction and aberration, which are very small, would be applied subsequently when the final corrections to the plate constants are determined.

In reference to the large differences between the measures and the Catalogue places, the following comparison of the places of stars common to the two Catalogues in the overlapping zone 64° 50′ and 65° 10′ is of interest :—

*Comparison of the Christiania* (64° 50′–70° 10′) *and Helsingfors-Gotha* (54° 50′–65° 10′) *Catalogues.*

| R.A. | Number of Stars. | Mean Discordance R.A. | Mean Discordance Dec. | Mean Difference of Declination Hel.-Chr. |
|---|---|---|---|---|
| h h | | s | ″ | ″ |
| 0–2 | 35 | ± ·125 | ± 0·98 | + ·15 |
| 2–4 | 24 | ± ·093 | ± 1·51 | + ·85 |
| 4–6 | 24 | ± ·135 | ± 1·32 | + ·44 |
| 6–8 | 26 | ± ·168 | ± 1·07 | + ·50 |
| 8–10 | 28 | ± ·104 | ± 0·74 | + ·18 |
| 10–12 | 29 | ± ·132 | ± 1·15 | + ·26 |
| 12–14 | 25 | ± ·084 | ± 0·88 | ·00 |
| 14–16 | 23 | ± ·120 | ± 0·94 | + ·44 |
| 16–18 | 25 | ± ·108 | ± 1·27 | + ·87 |
| 18–20 | 39 | ± ·124 | ± 1·25 | + ·85 |
| 20–22 | 45 | ± ·090 | ± 0·89 | + ·41 |
| 22–24 | 34 | ± ·123 | ± 1·05 | + ·94 |
| | 357 | ± ·123 | + 1 08 | + ·49 |

Including the systematic difference between the declinations, of the two Catalogues in the accidental error, the mean discordances between them are $\pm0^{s}\cdot123$ in R.A., and $1''\cdot08$ in Declination or expressing them both in arc, the probable errors of the differences are $\pm0''\cdot58$ and $\pm0''\cdot92$.

Of the plates taken for the Astrographic Catalogue at the Royal Observatory, about 130 have already been measured. The present rate of progress, now that an adequate staff has been organised under Mr. Hollis and a fixed routine adopted, is about 180 a year, 46 having been measured between October 1 and December 31, so that five or six years will be required to measure

all the plates. The parts of the sky already measured on pairs of overlapping plates are :—

| | | h m | h m | h m | h m |
|---|---|---|---|---|---|
| Decl. 65–66 | R.A. | 11 15 | – 1 21 | | |
| „ 66–67 | R.A. | 11 24 | – 0 0 | | |
| „ 67–68 | R.A. | 11 30 | – 0 0, | except 22 10 | – 22 30 |
| „ 68–69 | R.A. | 19 0 | – 20 0 | | |

Comparison of the measures with the right ascensions and declinations of the Helsingfors-Gotha or Christiania Catalogues, and determinations of plate constants, have been made for 72 plates ; the whole of this work having been done under the superintendence of Mr. Hollis. About 40 of these determinations have been made between October 1 and December 31, or at the rate of 160 plates a year.

## *Observations of Comet d* 1895 (*Brooks*) *made at the Royal Observatory, Greenwich.*

(*Communicated by the Astronomer Royal.*)

The observations were made with the Sheepshanks Equatorial, aperture 6·7 inches by taking transits over two cross-wires at right angles to each other, and each inclined 45° to the parallel of declination. Magnifying power 55.

| Greenwich Mean Solar Time. | | | | | Observer. | ☄−★R.A. | Corr. for Refraction. | Log factor of Parallax. | ☄−★N.P.D. | Corr. for Refraction. | Log factor of Parallax. | No. of Comps. | Apparent R.A. | Apparent N.P.D. | Comp. Star. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1895. | d | h | m | s | | m s | s | | ′ ″ | ″ | | | h m s | ° ′ ″ | |
| Dec. | 15 | 10 | 36 | 21 | A. C. | +1 27·85 | +0·01 | 9·6430 | −3 51·3 | −0·1 | 0·0776 | 6 | 6 20 30 98 | 25 58 49·1 | *a* |
| | 15 | 10 | 39 | 4 | ,, | −2 1·58 | −0·01 | 9·6350 | +4 36·0 | +0·1 | 0·0893 | 5 | 6 20 29·26 | 25 58 40·4 | *b* |

*Notes.*

The observations are corrected for refraction but not for parallax. They are also corrected for the error of inclination of the wires and for the motion of the comet.

The comet was a large, faint, diffused nebulosity, without nucleus, and difficult to observe.

The initials A.C. are those of Mr. Crommelin.

*Comparison Stars.*

| | Star's Name. | Assumed R.A. 1895·0. | Assumed N.P.D. 1895·0. | Authority. |
|---|---|---|---|---|
| | | h m s | ° ′ ″ | |
| *a* | B.D. + 63°, No. 647 | 6 18 53·72 | 26 2 43·7 | Equatorial comparison with star *c*. |
| *b* | B.D. + 64°, No. 590 | 6 22 21·41 | 25 54 6·9 | Helsingfors Gotha Ast. Gesell Catalogue. |
| *c* | O.A. (N.), 6995 | 6 27 55·31 | 26 3 51·1 | ,, ,, ,, ,, |

*Royal Observatory, Greenwich:*
1896 *January* 7.

## *Observations of Occultations of Stars by the Moon and of Phenomena of Jupiter's Satellites made at the Royal Observatory, Greenwich, in the year 1895.*

(*Communicated by the Astronomer Royal.*)

### *Occultations of Stars by the Moon.*

| Day. | Phenomenon. | Telescope. | Power. | Moon's Limb. | Mean Solar Time of Observation. h m | Observer. |
|---|---|---|---|---|---|---|
| 1895 Feb. 6 | Disapp. 49 Aurigæ | Sheepshanks Equat. | 100 | Dark | 5 48 58·99 | B. |
| 6 | ,, 49 Aurigæ | Altazimuth | 100 | ,, | 5 48 58·52 | C. D. |
| May 4 | ,, τ Leonis | Sheepshanks Equat. | 120 | ,, | 7 49 40·61 | H. |
| 4 | ,, τ Leonis | Astrographic Guid. Tel. | 120 | ,, | 7 49 40·74 | C. D. |
| 4 | ,, W.B. XI., 349 | Sheepshanks Equat. | 100 | ,, | 7 51 46·17 | H. |
| 4 | ,, W.B. XI., 349 | Astrographic Guid. Tel. | 120 | ,, | 7 51 46·20 | C. D. |
| 4 | ,, W.B. XI., 365 | Sheepshanks Equat. | 100 | ,, | 8 8 20·35 | H. |
| 4 | ,, W.B. XI., 365 | Astrographic Guid. Tel. | 120 | ,, | 8 8 20·77 | C. D. |
| 4 | ,, W.B. XI., 372 | ,, ,, ,, | 225 | ,, | 8 28 58·77 | ,, |
| 9 | Reapp. π Scorpii | Sheepshanks Equat. | 120 | ,, | 11 14 35·20 | A. C. |
| 11 (*a*) | Disapp. $\gamma^1$ Sagittarii | ,, ,, | 120 | Bright | 15 10 38·84 | H. |
| June 6 (*b*) | ,, τ Scorpii | Astrographic Guid. Tel. | 225 | ,, | 10 43 36·25 | H. F. |
| 6 (*c*) | Reapp. τ Scorpii | ,, ,, ,, | 225 | ,, | 10 58 46·85 | ,, |
| 26 | Disapp. Regulus | Altazimuth | 100 | Dark | 8 4 2·75 | H. |
| 26 | ,, Regulus | Sheepshanks Equat. | 120 | ,, | 8 4 3·25 | A. C. |
| 26 | Reapp. Regulus | Altazimuth | 100 | Bright | 8 54 58·21 | H. |

| Day. 1895. | Phenomenon. | Telescope. | Power. | Moon's Limb. | Mean Solar Time of Observation. h m s | Observer. |
|---|---|---|---|---|---|---|
| June 26 | Reapp. Regulus | Astrographic Guid. Tel. | 225 | Bright | 8 54 56·23 | J. |
| July 16 | „ 47 Arietis | Altazimuth | 100 | Dark | 13 26 55·68 | D. |
| 16 | „ 47 Arietis | Sheepshanks Equat. | 100 | „ | 13 26 55·17 | W. B. |
| Aug. 6 (*d*) | Disapp. 42 Aquarii | Astrographic Guid. Tel. | 225 | Bright | 12 25 4·06 | D.E. |
| 6 | Reapp. 42 Aquarii | Sheepshanks Equat. | 55 | Dark | 13 40 33·28 | A. C. |
| 7 (*e*) | Disapp. 81 Aquarii | Astrographic Guid. Tel. | 225 | Bright | 13 43 19·20 | J. |
| 7 | Reapp. 81 Aquarii | „ „ „ | 225 | Dark | 15 1 35·67 | „ |
| 7 | Disapp. 82 Aquarii | „ „ „ | 225 | Bright | 15 17 1·94 | „ |
| 12 | Reapp. Brad 355 | Sheepshanks Equat. | 100 | Dark | 10 0 50·41 | W. B. |
| Sept. 2 | Disapp. Aquarii | „ „ | 100 | „ | 13 52 12·44 | B. |
| 2 | Aquarii | Astrographic Guid. Tel. | 225 | „ | 13 52 12·14 | D. E. |
| 15 | Reapp. 83 Caneri | Altazimuth | 100 | „ | 15 34 40·41 | B. |
| 29 | Disapp. δ Capricorni | Sheepshanks Equat. | 100 | „ | 8 47 14·19 | C. M. |
| 29 | „ δ Capricorni | Astrographic Guid. Tel. | 225 | „ | 8 47 14·18 | R. C. |
| 29 (*f*) | Reapp. δ Capricorni | Sheepshanks Equat. | 100 | Bright | 10 7 27·01 | C. M. |
| 29 | „ δ Capricorni | Astrographic Guid. Tel. | 225 | „ | 10 7 25·05 | R. C. |
| 29 | „ δ Capricorni | Altazimuth | 100 | „ | 10 7 (30·67) | W. |
| 30 | Disapp. 58 Aquarii | Astrographic Guid. Tel. | 225 | Dark | 9 9 12·48 | D. E. |
| 30 | „ 58 Aquarii | Sheepshanks Equat. | 100 | „ | 9 9 12·51 | J. |

| Day. | Phenomenon. | Telescope. | Power. | Moon's Limb. | Mean Solar Time of Observation. h m s | Observer. |
|---|---|---|---|---|---|---|
| 1895. | | | | | | |
| Sept. 30 | Disapp. 58 Aquarii | Altazimuth | 100 | Dark | 9 9 13·38 | W. |
| Nov. 3 (*g*) | „ 19 Tauri | Astrographic Guid. Tel. | 225 | Bright | 13 28 29·92 | H. |
| 3 | Reapp. 19 Tauri | „ „ „ | 225 | Dark | 14 45 34·81 | „ |
| 3 | „ 19 Tauri | Sheepshanks Equat. | 55 | „ | 14 45 34·66 | A. C. |
| 3 (*h*) | „ 20 Tauri | Astrographic Guid. Tel. | 225 | „ | 14 51 (20·47) | H. |
| 3 | „ 20 Tauri | Sheepshanks Equat. | 55 | „ | 14 51 17·62 | A. C. |
| 3 (*i*) | „ 20 Tauri | Corbett Telescope | 100 | „ | 14 51 17·29 | R. C. |
| 10 | „ $\psi$ Virginis | Altazimuth | 100 | „ | 17 29 43·11 | A. C. |

*Notes.*

The occultations during the lunar eclipse on March 10 are not included in the above table, as these have been already communicated to the Society (*M.N.* lv. 6, p. 329).

(*a*) Not considered a good observation; Moon's limb boiling; star diffused. (*b*) Observation noted as doubtful; Moon's limb boiling; cloudy. (*c*) Moon's limb ill-defined, but observation considered better than disappearance. (*d*) Not considered a good observation. (*e*) Cloudy. (*f*) Not considered a good observation; star was not quite in contact with limb when first seen. (*g*) The star was projected on the Moon's disc $1\frac{1}{2}$ second before disappearance. Considered a bad observation. The count of seconds did not agree with the comparison with the clock after observation, and the observed time has therefore been increased $1^s$. (*h*) The observer noted probably late; he was looking at the clock just before, and probably lost the actual reappearance. The observed time has been diminished by $1^m$. (*i*) The observed time has been increased by $1^m$.

*Phenomena of Jupiter's Satellites.*

| Day. | Satellite. | Phenomenon. | Telescope. | Power. | Mean Solar Time of Observation. h m s | Mean Solar Time of N.A. h m s | Observer. |
|---|---|---|---|---|---|---|---|
| 1895 Jan. 9 | II. | Tr. Ing. First contact | 28-inch Equat. | 450 | 10 18 48 | 10 20 | L. |
| 9 | II. | Last contact | ,, | ,, | 10 22 15 | | ,, |
| 14 | III. | Occ. D. Last seen | Sheepsh. Equat. | 55 | 6 45 53 | 6 43 | H. F. |
| 18 | II. | Ecl. R. First seen | ,, | 200 | 11 23 14 | | C. D. |
| 18 | II. | Bisection | ,, | ,, | 11 25 2 | 11 23 58 | ,, |
| 18 | II. | Full brightness | ,, | ,, | 11 26 42 | | ,, |
| 18 | I. | Tr. Ing. First contact | ,, | 100 | 12 52 56 | | ,, |
| 18 | I. | Bisection | ,, | ,, | 12 54 25 | 12 52 | ,, |
| 18 | I. | Last contact | ,, | ,, | 12 56 50 | | ,, |
| 21 | III. | Occ. D. First contact | ,, | 200 | 10 2 18 | | A. C. |
| 21 | III. | Bisection | ,, | ,, | 10 4 23 | 10 5 | ,, |
| 21 | III. | Last seen | ,, | ,, | 10 8 10 | | ,, |
| 21 | III. | Occ. R. Last contact | ,, | ,, | 12 52 47 | 12 54 | ,, |
| 21 | III. (*a*) | Ecl. D. Began to fade | ,, | ,, | 12 56 58 | 13 2 49 | ,, |
| 21 | III. | Last seen | ,, | ,, | 13 2 1 | | ,, |
| 25 | II. | Occ. D. First contact | ,, | ,, | 9 45 9 | | ,, |
| 25 | II. | Bisection | ,, | ,, | 9 47 57 | 9 49 | ,, |
| 25 | II. | Last seen | ,, | ,, | 9 51 7 | | ,, |

| Day. | Satellite. | Phenomenon. | Telescope. | Power. | Mean Solar Time of Observation. h m s | Mean Solar Time of N A. h m s | Observer. |
|---|---|---|---|---|---|---|---|
| Jan. 28 | I. | Ecl. R. First seen | Sheepsh. Equat. | 200 | 9 20 42 | 9 21 | H. |
| 28 | I. | Full brightness | ,, | ,, | 9 22 26 | | ,, |
| Feb. 11 | I. | Occ. D. First contact | ,, | 120 | 9 49 47 | 9 52 | B. |
| 11 | I. | Last seen | ,, | ,, | 9 53 36 | | ,, |
| 11 | I. | Ecl. R. First seen | ,, | ,, | 13 12 10 | 13 12 6 | ,, |
| 19 | II. | Occ. D. First contact | ,, | ,, | 6 7 1 | 6 8 | ,, |
| 19 | II. | Last seen | ,, | ,, | 6 11 11 | | ,, |
| 19 | III. | Ecl. R. First seen | ,, | ,, | 7 53 3 | 7 55 18 | ,, |
| 19 | I. | Tr. Ing. First contact | ,, | ,, | 8 57 24 | 8 58 | ,, |
| 19 | I. | Bisection | ,, | ,, | 9 0 33 | | ,, |
| 19 | I. | Last contact | ,, | ,, | 9 3 33 | | ,, |
| 19 | II. | Ecl. R. First seen | ,, | ,, | 11 2 3 | 11 3 8 | ,, |
| 19 | I. | Tr. Egr. First contact | ,, | ,, | 11 9 52 | 11 15 | ,, |
| 19 | I. | Bisection | ,, | ,, | 11 13 21 | | ,, |
| 19 | I. | Last contact | ,, | ,, | 11 16 31 | | ,, |
| 19 | IV. | Ecl. D. Last seen | ,, | ,, | 13 47 36 | 13 24 6 | ,, |
| Mar. 14 | II. (*b*) | Tr. Ing. First contact | ,, | ,, | 8 22 27 | 8 21 | H. F. |
| 14 | II. | Bisection | ,, | ,, | 8 24 41 | | ,, |
| 14 | II. | Last seen | ,, | ,, | 8 25 45 | | ,, |

| Day. | Satellite. | Phenomenon. | Telescope. | Power. | Mean Solar Time of Observation. h m s | Mean Solar Time of N.A. h m s | Observer. |
|---|---|---|---|---|---|---|---|
| Mar. 14 | II. (*c*) | Tr. Egr. Last contact | Altaz. | 100 | 11 2 59 | 10 59 | H. F. |
| Apr. 23 | I. | Ecl. R. First seen | Sheepsh. Equat. | 140 | 8 29 1 | 8 28 58 | A. C. |
| 23 | I. | Full brightness | ,, | ,, | 8 30 35 | | ,, |
| 24 | II. | Ecl. R. First seen | ,, | 200 | 10 21 47 | 10 22 34 | H. |
| 24 | II. | Full brightness | ,, | ,, | 10 24 2 | | ,, |
| May 8 | I. | Tr. Egr. First contact | ,, | 200 | 8 31 56 | 8 34 | ,, |
| 8 | I. | Last contact | ,, | ,, | 8 36 11 | | ,, |
| Nov. 14 | I. | Ecl. D. Last seen | ,, | 120 | 13 22 12 | 13 21 41 | B. |
| 14 | IV. | Ecl. D. Last seen | ,, | ,, | 13 48 18 | 13 42 22 | ,, |
| 18 | III. | Ecl. D. Began to fade | ,, | ,, | 12 24 35 | 12 30 34 | A. C. |
| 18 | III. | Last seen | ,, | ,, | 12 31 57 | | ,, |
| 23 | I. | Occ. R. First seen | ,, | ,, | 13 9 6 | | ,, |
| 23 | I. | Bisection | ,, | ,, | 13 11 9 | 13 11 | ,, |
| 23 | I. | Last contact | ,, | ,, | 13 13 8 | | ,, |
| 23 | IV. | Tr. Egr. Last contact | ,, | ,, | 13 38 1 | 13 51 | ,, |
| 23 | II. | Ecl. D. Began to fade | ,, | ,, | 13 40 26 | 13 42 45 | ,, |
| 23 | II. | Last seen | ,, | ,, | 13 44 32 | | ,, |

| Day. | Satellite. | Phenomenon | Telescope. | Power. | Mean Solar Time of Observation. h m s | Mean Solar Time of N.A. h m s | Observer. |
|---|---|---|---|---|---|---|---|
| Nov. 30 | I. (*d*) | Ecl. D. Began to fade | Sheepsh. Equat. | 120 | 11 35 20 | 11 36 16 | A. C. |
| 30 | I. | Last seen | ,, | ,, | 11 36 52 | | ,, |
| Dec. 7 | I. | Ecl. D. Began to fade | ,, | 55 | 13 28 11 | 13 29 31 | S. |
| 7 | I. | Last seen | ,, | ,, | 13 29 46 | | ,, |
| 31 | I. | Tr. Ing. Bisection | ,, | 200 | 11 30 50 | 11 30 | H. |
| 31 | I. | Last contact | ,, | ,, | 11 33 35 | | ,, |
| 31 | III. | Ecl. D. Last seen | ,, | ,, | 12 20 10 | 12 18 55 | ,, |

*Notes.*

(*a*) Too near Jupiter for accurate observation. (*b*) Very cloudy. (*c*) Very cloudy.
(*d*) Not a very good observation; sky bright, slight haze.

The aperture of the 28-inch Equatorial is 28 inches, of the Astrographic Guiding Telescope 10 inches, of the Sheepshanks Equatorial 6·7 inches, of the Corbett Telescope 6·5 inches, and of the Altazimuth 4 inches.

The initials D., L., H., A. C., B., H. F., C. M., C. D., R. C., D. E., W. B., J., S., and W., are those of Mr. Dyson, Mr. Lewis, Mr. Hollis, Mr. Crommelin, Mr. Bryant, Mr. Furner, Mr. Martin, Mr. Davidson, Mr. Cheeseman, Mr. Edney, Mr. Bowyer, Mr. Johns, Mr. Showell, and Mr. Witchell respectively.

## *On the Drift of the Surface Material of Jupiter in different Latitudes.* By A. Stanley Williams.

The remarkable appearance presented by the great red spot on *Jupiter* in 1879 and subsequent years gave a great impetus to the physical observation of this planet. Notwithstanding, however, the numerous important investigations which resulted therefrom, and the many determinations of the period of rotation made from different markings in various latitudes, the question of the drift, or various rates of rotation, of the surface material in different latitudes still seems to be properly understood by only a very few. This is doubtless due in great measure to the fact that the chief investigations on the subject are scattered through the various publications of the years immediately following the apparition of the red spot, many of them not being very accessible, and that little has yet been done to bring together and adequately discuss the abundant existing material.

A great many determinations of rotation period in various latitudes were discussed by M. Belopolsky in a valuable paper published a few years ago,* the existence of the great equatorial current receiving full recognition. But, owing principally to the circumstance that a large number of results based on insufficient material were included in this discussion, the various minor, but yet very important, currents escaped notice.

In the present paper most of the chief thoroughly satisfactory determinations of rotation period are brought together and discussed under the heads of the different atmospheric currents to which they refer. The original sources of information have been referred to in nearly every case, and although it is probable that some first-class determinations may have been omitted, yet it is believed that all those contained in this paper are thoroughly to be relied upon. A good many results have been rejected from various causes; such as uncertainty as to the correct identification of the markings observed, or the short period of time over which the observations extend. And all determinations based solely upon positions derived from sketches have been rigidly excluded, experience having shown that such results are quite unreliable, except, possibly, in a few cases where the observations extend over very long periods of time.

In the present state of our knowledge there are nine distinct atmospheric currents recognisable upon *Jupiter*. Others will doubtless be added as our acquaintance with the planet becomes more intimate. But these nine currents are absolutely certain, and their boundaries are also well established within narrow limits, although it seems probable that, in some cases at least, these boundaries may vary slightly in position from time to time.

* "Ueber die Rotation des Jupiter," Mélanges mathématiques et astron. tirés du *Bulletin de l'Acad. impériale des Sciences de St.-Pétersbourg*, t. vii. 104.

With one exception the different atmospheric currents completely encircle the planet. They have therefore been arranged in zones, and numbered in order from north to south. After the number of the zone, or current, will be found the zenographical latitudes * of the north and south borders of the current. These limits are based chiefly upon my own observations and measures from 1879 to the present time, assisted by measured positions from photographs of *Jupiter* taken at the Lick Observatory. After the limits of latitude of each zone is the adopted average value of the period of rotation, R. This is not always the simple mean of the different results, and is to some extent a personal estimate of the average value. Lastly comes a complete list of the determinations of rotation period, with a short discussion of the results.

In these lists of determinations will be found :—(1) The year or years in which the observations on which the determination is based were made. (2) The period of rotation. (3) Some figures whereby some idea may be formed as to the degree of accuracy of the different results. A number followed by the letter *r* indicates the number of rotations of the planet elapsed between the first and last observations on which the period depends. A number followed by the letter *d* signifies the number of days covered by the observations. A number followed by the letter *s* gives the number of spots, where more than one was observed, the value of R in the second column being then the mean of the periods of these spots. It should be stated here that a rotation period based in this way upon several spots is much more to be relied upon for our purpose than is one derived from a single spot, however well observed. For in every zone of *Jupiter* the individual spots are found to have slightly different periods of rotation, showing that they have slight proper motions of their own. (4) The authority for the determination.

*Zone I.—Lat.* $+85°$ *to* $+28°$. $R = 9^h\ 55^m\ 37^s{\cdot}5$.

| | h m s s | | | |
|---|---|---|---|---|
| 1862 | R = 9 55 25·7 | 128r | Schmidt | *a* |
| 1880 | 32·5 ± 0·77 | 94r | O. Lohse | *b* |
| 1880 | 35·7 | 2s | Hough | *c* |
| 1881 | 42·4 ± 3·33 | 159r | O. Lohse | *d* |
| 1888 | 40 8 | 9s | Williams | *e* |
| 1892 | 38·9 ± 1·20 | 3s | ,, | *f* |
| 1894-5 | 39·0 | 2s | Denning | *g* |

*Notes.*—(*a*) Isolated dark spot in $+30°$. (*b*) Small dark spot in about $+34°$. (*c*) Two black spots on belt 2. (*d*) Bright spot in north polar cap. (*e*) Dark streaks extending from $+15°$ to $+70°$. (*f*) Dark streaks extending from $+40°$ to $+85°$. (*g*) Two black spots in about $+35°$.

* These have been derived by means of the table by Dr. O. Lohse, published in *Publicationen des Astrophysikalischen Observatoriums zu Potsdam*, No. 9, p. 7.

There is some evidence of a slight increase in the rate of rotation since 1862.

*Zone II.—Lat.* $+28°$ *to* $+24°$. $R=9^h\ 54\frac{1}{2}^m$ *to* $9^h\ 56\frac{1}{2}^m$.

The region about the second dark belt north of the equator (the north temperate belt=belt No. 3 of Professor Hough and belt No. 4 of Dr. Terby) is certainly one of the most remarkable regions of the whole planet. Here in close juxtaposition have been found both the quickest and the slowest of the great Jovian atmospheric currents. Zone II. occupies the northern half of the above-mentioned belt, and includes also the greater part of the light region intervening between it and the next dark belt to the north. Usually the drift of the surface material in Zone II. appears to differ little from that indicated by the red spot. For instance, in 1888 a number of dark streaks were visible having a north and south direction, and extending from N. lat. 60°–70° uninterruptedly across the zone. The mean value of R from nine of these streaks was $9^h\ 55^m\ 40^s{\cdot}8$, as given under Zone I. Some dark spots on the north temperate belt itself also rotated at a similar rate. But in the apparition of 1891–92 the region of this belt was in an abnormally disturbed state. A large protuberant mass on the north side of the belt was then observed to rotate for a time in a period of $9^h\ 54^m\ 31^s$.* In the succeeding opposition of *Jupiter* a great many spots, both light and dark, were visible on the north side of the belt. These had rotation periods considerably longer than that of the red spot. The exact average rate of rotation at this time is uncertain at present, as there were considerable variations in the case of different spots, and the observations, which are numerous, have only as yet been partially reduced. It cannot, however, well be shorter than the value, $9^h\ 56\frac{1}{2}^m$, stated above. Shortly, then, the facts in connection with this zone are as follows :—Usually the drift of the surface material is almost exactly at the same rate as the red spot. But at times, when the region is in a disturbed state, the rotation period may be as short as $9^h\ 54\frac{1}{2}^m$, or as long as $9^h\ 56\frac{1}{2}^m$. Both rates are given in the little table at the end of this paper ; the latter in order to emphasise the enormous contrast at times existing between the velocity of the surface drift in this zone and in the adjacent Zone III.

*Zone III.—Lat.* $+24°$ *to* $+20°$. $R=9^h\ 48^m$ *to* $9^h\ 49\frac{1}{2}^m$.

In 1880 and again in 1891 an eruption of dark spots broke out on the south edge of the north temperate belt. These spots had a rapid movement from east to west compared with all other objects. The exact rate of rotation in 1880 is uncertain, but appears to have been about $9^h\ 48^m$. The observations, which

* Some particulars about this spot will be found in the *Observatory*, 1892, p. 112.

are numerous, are scattered through the publications of the time, and have never yet been properly discussed. Doubtless, as in 1891, the individual spots differed considerably amongst themselves as regards their rate of motion.

Some account of the disturbance of 1891 will be found in the *Observatory*, 1892, pp. 109–112, and also in a letter by Mr. Denning on p. 147 of the same periodical. Shortly it may be stated that the average rotation period was about $9^h\ 49\frac{1}{2}^m$, but that there were considerable differences in the rate of motion of the individual spots, and that in more than one instance sudden changes of considerable amount occurred in the velocities of some of these spots. It is a matter of great importance to determine whether this enormously swift current of Zone III. is a permanent current, or only a temporary one arising when the region is in a state of unusual disturbance. In the succeeding opposition of 1892, although the disturbance had in great measure subsided, yet a number of minute black spots were still visible on the south edge of the belt, and these moved with much the same velocity as the spots of the previous year had done. This would imply considerable permanence at least in this atmospheric current.

The great contrast between the velocity of the surface drift in the two adjacent Zones II. and III. has already been alluded to when treating of the former zone. Taking the extreme values, the difference of velocity amounts to close on 400 miles (644 kilometres) per hour. Why this enormous difference should exist between the velocities of two comparatively narrow atmospheric currents lying side by side in almost the same north latitude is a mystery at present, like so many others of the phenomena of *Jupiter*. Of the certainty of the fact, however, there is no doubt, and it must be taken into account in every theory of the planetary constitution.

*Zone IV.—Lat.* + 20° *to* + 10°. $R. = 9^h\ 55^m\ 33^s.9$.

| | h m s s | | |
|---|---|---|---|
| 1787 | R = 9 55 33·6 | 242r | Schroeter |
| 1835 | 21·3 | 225r | Airy (from obs. by Glaisher) |
| 1835 | 26·5 ± 0·17 | 2s | Beer and Mädler |
| 1866 | 18·3 | 138r | Schmidt |
| 1881 | 35·2 ± 0·85 | 166r | O. Lohse |
| 1887 | 34·5 | 2s | Terby |
| 1887 | 36·5 | 17s | Williams |
| 1888 | 40·9 | 18s | „ |
| 1890 | 34·5 | 5s | Hough |
| 1890-1 | 38·3 | 831r | Denning |
| 1891 | 27·4 | 119d | Hough |
| 1894-5 | 35·0 | 9s | Denning |

The markings observed consist of white and dark spots on the north side of the north equatorial belt and in the bright zone separating that belt from the north temperate belt. On the whole the agreement between the different results is close and satisfactory. It is certain, too, that some of the differences are due to real slight variations in the velocity of the drift. There seems, however, to have been no permanent sensible change in this velocity since the first determination by Schroeter in 1787.

*Zone V.—Lat.* + 10° *to* − 12°. $R = 9^h\ 50^m\ 20^s$.

| | h m s s | | |
|---|---|---|---|
| 1879 | R=9 49 59 | 256r | O. Lohse |
| 1879–80 | 50 3·5 | 302d | Hough |
| 1880 | 50 8·4 ±0·22 | 504r | O. Lohse |
| 1880 | 50 0 | 78r | Schmidt |
| 1880 | 49 53·5 | ... | Kortazzi |
| 1880 | 50 4·5 | 2s | Denning |
| 1880–1 | 5 | ... | „ |
| 1880–1 | 6·6 | 89d | Marth (from obs. by several observers) |
| 1880–1 | 7 | 55d | Kortazzi |
| 1880–1 | 5·1 | 2s | Hough |
| 1881 | 10·7 ±1·78 | 127r | O. Lohse |
| 1880–2 | 7·42 | ... | Marth (from obs. by several observers) |
| 1880–2 | 9·8 | ... | Hough |
| 1881–2 | 9·8 | 252d | „ |
| 1882–3 | 9·8 | ... | „ |
| 1882–3 | 9·6 | ... | Denning |
| 1880–5 | 9·84 | ... | Marth (from obs. by several observers) |
| 1882–4 | 12·25 | ... | Marth (from obs. by several observers) |
| 1883–4 | 12·7 | ... | Hough |
| 1883–4 | 12·1 | ... | Denning |
| 1884–5 | 8·2 | 261d | Hough |
| 1885 | 14·34 | ... | Denning |
| 1885 | 15·88 | ... | Marth (in his ephemeris for 1886–7) |
| 1886 | 22·9 | 112r | Williams (from obs. by Denning) |
| 1887 | 22·4 | 21s | Williams |
| 1888 | 30·0 | 2s | Marth (from obs. by Williams) |
| 1888 | 34·3 | 275r | Williams |
| 1891 | 26·4 | 99l | Hough |

This zone is the zone of the great equatorial current, which was discovered by Cassini in the latter part of the seventeenth century. The determinations of the value of R since the time of this astronomer have been very numerous, as will be seen from the foregoing list. One of the most remarkable circumstances revealed by this list is the continual increase in the length of the period of rotation, amounting in ten years to about half a minute of time. At present the period seems to be still longer, the average duration for the whole zone being now probably about $9^h\ 50^m\ 40^s$. A new determination during the present opposition, based on observations of as many spots as possible, is much to be desired.

All the results contained in the above list refer to spots situated on the south side of the equator. Usually the markings lying on the north side of the equator have rotated at nearly the same rate as those situated south of the equator, but in 1887 the former rotated somewhat more slowly than the latter, and the same thing seems to have occurred in 1882. This will be seen from the following determinations of rotation period from spots lying on the north side of the equator, compared with those for corresponding years in the previous list.

| | h m s | | |
|---|---|---|---|
| 1882 | R = 9 51 40 | 27d | Denning |
| 1884–5 | 50 9·2 | 238d | Hough |
| 1887 | 50 40·1 | 5s | Williams |
| 1891 | 50 31·6 | 69d | Hough |

*Zone VI.—Lat.* − 12° *to* − 18°. $R = 9^h\ 55^m\ 40^s$.

The great equatorial current of Zone V. extends so far south as usually to include at least one half of the south equatorial belt. This belt is generally double, appearing composed of two dark bands separated by a narrow clear interval. The material of the southernmost component appears, however, usually to rotate at about the same rate as the red spot. The great bay in the south equatorial belt opposite the latter is well known. This, however, in itself, would not prove that the material of the belt rotates at the same rate as the spot. The following results show, however, that the surface material did rotate at approximately the same rate as the red spot in the under-mentioned years.

| | h m s | | |
|---|---|---|---|
| 1877 | R = 9 55 40·5 | 567r | Trouvelot |
| 1877–9 | 36·7 | 2076r | ,, |
| 1884–5 | 43·5 | 2s | Hough |

*Zone VII.—Lat.* − 14° *to* − 28°. $R = 9^h\ 55^m\ 40^s$.

This zone comprises the great red spot, and is really only part of a zone, since it is confined to a comparatively small region

of little more than 36° of longitude in extent. All the rest of the surface south of the south equatorial belt, and in the same latitude as the red spot, is comprised in the succeeding Zone VIII. The determinations of the rotation period of the red spot are very numerous and well known, and it is unnecessary to give them here.

*Zone VIII.—Lat.* − 18° *to* − 37°. $R = 9^h\ 55^m\ 18^s{\cdot}1$.

| | h m s s | | |
|---|---|---|---|
| 1787 | R=9 55 17·6 | 250r | Schroeter |
| 1862 | 17·2 | 128r | Schmidt |
| 1872–3 | 19·6 ±2·34 | ... | O. Lohse |
| 1880 | 16·18 | ... | Barnard |
| 1880–1 | 17·9 | ... | Denning |
| 1880–1 | 19 07 | ... | Barnard |
| 1887 | 18 | 55d | Terby |
| 1887 | 17·1 | 3s | Williams |
| 1889 | 16·7 ±0·33 | 263r | ,, |
| 1889 | 19·0 ±0·26 | 326r | ,, |
| 1890–1 | 18·3 | 1296r | Denning |
| 1891 | 18·2 | 53r | ,, |
| 1891 | 20 | 2s | Hough |

The drift of the surface material has been remarkably uniform in this zone, no material change having taken place since the first determination by Schroeter more than 100 years ago. In fact this atmospheric current is undoubtedly the most steady one of which we have any record. Most of the results contained in the above list relate to markings in about −30°. The first determination of 1889 relates, however, to a dark spot in the northernmost part of the zone, and having a dark streak extending southwards to about lat. −28°. Many unpublished observations by the writer of white spots in the bright zone south of the south equatorial belt show that the white surface material of this region has a similar motion. In the midst of this atmospheric current the great red spot emerges, as it were, like an island in a river.

*Zone IX.—Lat.* − 37° *to* − 55°. $R = 9^h\ 55^m\ 5^s$.

| | h m s s | | | |
|---|---|---|---|---|
| 1886 | R=9 55 11·14 | ... | Young | *a* |
| 1888 | 0·9 ±0·97 | 2s | Williams | *b* |
| 1890 | 6·7 ±0·21 | 28or | ,, | *c* |

*Notes.*—(*a*) Small white spot in lat. 50° south. (*b*) Lat. −37° to −55°. (*c*) Lat. −36° to −47°.

The existence of this comparatively swift current so far south is a rather curious anomaly. The drift of the material near the south pole still remains to be ascertained, and the anomalous nature of this current renders it important to solve this question.

*Summary of Zones.*

| | | | h m s | h m |
|---|---|---|---|---|
| Zone | I. | Lat. +85° to +28° | R=9 55 37·5 | |
| ,, | II. | +28 ,, +24 | 9 54½ to | 9 56½ |
| ,, | III. | +24 ,, +20 | 9 48 to | 9 49½ |
| ,, | IV. | +20 ,, +10 | 9 55 33·9 | |
| ,, | V. | +10 ,, −12 | 9 50 20 | |
| ,, | VI. | −12 ,, −18 | 9 55 40 | |
| ,, | VII. | −14 ,, −28 | 9 55 40 | |
| ,, | VIII. | −18 ,, −37 | 9 55 18·1 | |
| ,, | IX. | −37 ,, −55 | 9 55 5 | |

Zone VII. is incomplete, being confined to the red spot.

A glance at the above table, in which the results for the different zones are summarised, will show how anomalous and unsymmetrical are most of the currents. In particular, the northern hemisphere differs altogether from the southern hemisphere. In the latter the very remarkable region about lat. + 25° is absent altogether. Possibly the presence of the great red spot may have had something to do with this. On the other hand, the northern hemisphere lacks the red spot and the two moderately swift currents of Zones VIII. and IX., the surface drift being nearly uniform from lat. + 28° almost to the pole.*

One of the most remarkable peculiarities about these atmospheric currents of *Jupiter*, is that they circulate in a due east and west direction, and show little or no sign of movement toward or from the poles. They appear also to be usually sharply bounded, one current by another, without indication of a gradual transition from one to another, though there are exceptions to this rule. Any circulation in a north and south direction would seem to take place chiefly by means of the narrow rifts and streamers seen to traverse obliquely some of the belts and clear zones of *Jupiter*. But this subject has only just begun to be investigated by students of the planet.

It has sometimes been stated that *Jupiter* has a certain amount of resemblance to the Sun, inasmuch as in both orbs the rotation is most rapid near the Equator. I have therefore added the following table in which the solar rotation period, as com-

* A difference of one minute in the period of rotation of two currents near *Jupiter's* equator signifies a real difference of 45 miles (72 kilometres) per hour in the velocities of such currents.

puted by Spoerer's formula,* is given for the latitudes corresponding to the centres of the different zones of *Jupiter*. The rotation periods for both orbs are also expressed in terms of that for their respective equatorial zones, as this will bring out better the *relative* drifts of the solar and jovian currents :—

| | *Jupiter.* | | *The Sun.* | |
|---|---|---|---|---|
| Latitude. | Rotation period for different latitudes | | Rotation period for different latitudes | |
| | In time. | In terms of the Equatorial period. | In days. | In terms of the Equatorial period. |
| | h m s | | d | |
| +46° | 9 55 37·5 | 1·0089 | 28·625 | 1·1407 |
| +26 | 9 54 30 | 1·0071 | 26·165 | 1 0427 |
| | 9 56 30 | 1 0104 | | |
| +22 | 9 48 45 | 0·9973 | 25·855 | 1·0303 |
| +15 | 9 55 33·9 | 1·0089 | 25·445 | 1·0140 |
| 0 | 9 50 20 | ... | 25·094 | ... |
| −15 | 9 55 40 | 1·0090 | 25·445 | 1·0140 |
| −21 | 9 55 40 | 1·0090 | 25·786 | 1·0276 |
| −27½ | 9 55 18·1 | 1·0084 | 26·295 | 1 0478 |
| +46 | 0 55 5 | 1·0081 | 28·625 | 1·1407 |

## *Ephemeris for Physical Observations of the Moon*, 1896.

By A. Marth.

| Greenwich Noon. | Selenographical Colong. of the Sun. | Lat. | Geocentric Libration. Sel. Long. of the Earth. | Lat. | Combined Amount. | Direction. |
|---|---|---|---|---|---|---|
| 1896. | ° | ° | ° | ° | ° | ° |
| Jan. 19 | 321·23 | −0·91 | −0·55 | −1·80 | 1·88 | 163·0 |
| 20 | 333·41 | 0·89 | 1·77 | 3·09 | 3·61 | 150 2 |
| 21 | 345·58 | 0·87 | 3·15 | 4·25 | 5·29 | 143·5 |
| 22 | 357·74 | 0·85 | 4·43 | 5·24 | 6·86 | 139·9 |
| 23 | 9·90 | 0·83 | 5 51 | 6·02 | 8·15 | 137 7 |
| 24 | 22·05 | 0·81 | 6·31 | 6·53 | 9·07 | 136·2 |
| 25 | 34·20 | −0·78 | −6·76 | −6·75 | 9·54 | 135 2 |
| 26 | 46·34 | 0·76 | 6·80 | 6·62 | 9·48 | 134 4 |
| 27 | 58·48 | 0·73 | 6·43 | 6·13 | 8·87 | 133·8 |
| 28 | 70·62 | 0·70 | 5·64 | 5·27 | 7·71 | 133·2 |
| 29 | 82·75 | 0·67 | 4·49 | 4·05 | 6·04 | 132·1 |
| 30 | 94·87 | 0·64 | 3·06 | 2·55 | 3·98 | 129 8 |
| 31 | 106·00 | −0·61 | −1·47 | −0·88 | 1·71 | 120·9 |

* Daily angular rotation: $\xi = 8°{\cdot}548 + 5°{\cdot}798 \cos$ latitude. *Publ. des Astrophysik. Obser. zu Potsdam*, Band x. p. 145. [I am indebted to Mr. E. W. Maunder for the above Table.]

| Greenwich Noon. | Selenographical Colong. of the Sun. | Lat. | Geocentric Libration. Sel. Long. of the Earth. | Lat. | Combined Amount. | Direction. |
|---|---|---|---|---|---|---|
| 1896. | ° | ° | ° | ° | ° | ° |
| Feb. 1 | 118·13 | −0·58 | +0·18 | +0·90 | 0·92 | 348·7 |
| 2 | 131·27 | 0·55 | 1·77 | 2·60 | 3·15 | 325·8 |
| 3 | 143·41 | 0·52 | 3·20 | 4·10 | 5·20 | 322·1 |
| 4 | 155·56 | 0·49 | 4·40 | 5·32 | 6·90 | 320·5 |
| 5 | 167·72 | 0·46 | 5·32 | 6·19 | 8·16 | 319·5 |
| 6 | 179·88 | −0·44 | +5·95 | +6·68 | 8·93 | 318·5 |
| 16 | 301·76 | −0·19 | −1·02 | −2·82 | 3·00 | 160·1 |
| 17 | 313·95 | 0·16 | 2·42 | 4·03 | 4·70 | 149·1 |
| 18 | 326·14 | 0·13 | 3·78 | 5·07 | 6·32 | 143·4 |
| 19 | 338·32 | 0·11 | 5·04 | 5·90 | 7·75 | 139·6 |
| 20 | 350·50 | 0·08 | 6·12 | 6·49 | 8·91 | 136·9 |
| 21 | 2·67 | 0·05 | 6·96 | 6·79 | 9·71 | 134·5 |
| 22 | 14·84 | −0·03 | −7·50 | −6·77 | 10·09 | 132·3 |
| 23 | 27·00 | 0·00 | 7·66 | 6·41 | 9·97 | 130·1 |
| 24 | 39·16 | +0·03 | 7·42 | 5·70 | 9·35 | 127·7 |
| 25 | 51·31 | 0·06 | 6·73 | 4·64 | 8·17 | 124·7 |
| 26 | 63·46 | 0·09 | 5·62 | 3·26 | 6·60 | 119·7 |
| 27 | 75·60 | 0·13 | 4·13 | −1·63 | 4·44 | 111·6 |
| 28 | 87·74 | +0·16 | −2·35 | +0·14 | 2·35 | 86·4 |
| 29 | 99·88 | 0·19 | −0·41 | 1·93 | 1·97 | 12·0 |
| Mar. 1 | 112·02 | 0·22 | +1·56 | 3·57 | 3·90 | 336·4 |
| 2 | 124·17 | 0·25 | 3·39 | 4·96 | 6·01 | 325·7 |
| 3 | 136·32 | 0·28 | 4·95 | 5·98 | 7·58 | 320·5 |
| 4 | 148·48 | 0·31 | 6·17 | 6·60 | 9·02 | 317·1 |
| 5 | 160·64 | +0·34 | +6·98 | +6·81 | 9·74 | 314·5 |
| 17 | 307·02 | +0·63 | −3·92 | −5·69 | 6·91 | 145·5 |
| 18 | 319·23 | 0·65 | 5·09 | 6·32 | 8·11 | 141·3 |
| 19 | 331·43 | 0·68 | 6·10 | 6·68 | 9·04 | 137·8 |
| 20 | 343·63 | 0·70 | 6·92 | 6·74 | 9·65 | 134·4 |
| 21 | 355·82 | 0·73 | 7·48 | 6·48 | 9·88 | 131·1 |
| 22 | 8·00 | 0·75 | 7·75 | 5·89 | 9·72 | 127·4 |
| 23 | 20·18 | +0·78 | −7·66 | −4·97 | 9·12 | 123·1 |
| 24 | 32·36 | 0·80 | 7·17 | 3·75 | 8·09 | 117·7 |
| 25 | 44·53 | 0·83 | 6·27 | 2·27 | 6·67 | 109·9 |
| 26 | 56·69 | 0·86 | 4·96 | −0·60 | 5·00 | 96·9 |
| 27 | 68·85 | 0·88 | 3·29 | +1·15 | 3·49 | 70·7 |
| 28 | 81·01 | +0·91 | −1·35 | +2·85 | 3·15 | 25·3 |

| Greenwich Noon. | Selenographical Colong. of the Sun. | Selenographical Lat. of the Sun. | Geocentric Libration. Sel. Long. of the Earth. | Geocentric Libration. Lat. of the Earth. | Geocentric Libration. Combined Amount. | Geocentric Libration. Direction. |
|---|---|---|---|---|---|---|
| 1896. | ° | ° | ° | ° | ° | ° |
| Mar. 29 | 93·16 | +0·94 | +0·72 | +4·35 | 4·41 | 350·6 |
| 30 | 105·32 | 0·96 | 2·75 | 5·54 | 6·18 | 333·7 |
| 31 | 117·48 | 0·98 | 4·58 | 6·33 | 7·81 | 324·2 |
| Apr. 1 | 129·64 | 1·01 | 6·05 | 6·68 | 9·00 | 318·0 |
| 2 | 141·81 | 1·03 | 7·07 | 6·61 | 9·67 | 313·3 |
| 3 | 153·99 | 1·05 | 7·59 | 6·16 | 9·76 | 309·2 |
| 4 | 166·17 | +1·07 | +7·63 | +5·39 | 9·33 | 305·4 |
| Apr. 14 | 288·31 | +1·22 | −3·78 | −6·12 | 7·19 | 148·4 |
| 15 | 300·54 | 1·24 | 4·79 | 6·51 | 8·08 | 143·8 |
| 16 | 312·76 | 1·25 | 5·63 | 6·61 | 8·67 | 139·7 |
| 17 | 324·98 | 1·27 | 6·20 | 6·39 | 8·90 | 136·0 |
| 18 | 337·19 | 1·28 | 6·77 | 5·86 | 8·95 | 131·1 |
| 19 | 349·40 | +1·30 | −7·02 | −5·03 | 8·63 | 125·8 |
| 20 | 1·61 | 1·31 | 6·98 | 3·91 | 7·99 | 119·4 |
| 21 | 13·81 | 1·33 | 6·63 | 2·55 | 7·11 | 111·1 |
| 22 | 26·00 | 1·35 | 5·95 | −1·00 | 6·03 | 99·6 |
| 23 | 38·19 | 1·36 | 4·90 | +0·64 | 4·94 | 82·5 |
| 24 | 50·37 | +1·38 | 3·50 | 2·28 | 4·18 | 56·9 |
| 25 | 62·55 | 1·39 | −1·81 | 3·80 | 4·17 | 24·2 |
| 26 | 74·72 | 1·40 | +0·09 | 5·07 | 5·07 | 359·0 |
| 27 | 86·89 | 1·42 | 2·02 | 5·99 | 6·32 | 341·4 |
| 28 | 99·06 | 1·43 | 3·83 | 6·48 | 7·52 | 329·5 |
| 29 | 111·24 | +1·44 | +5·35 | +6·54 | 8·44 | 320·9 |
| 30 | 123·42 | 1·45 | 6·45 | 6·19 | 8·93 | 313·9 |
| May 1 | 135·60 | 1·46 | 7·07 | 5·48 | 8·94 | 307·9 |
| 2 | 147·79 | 1·46 | 7·19 | 4·49 | 8·47 | 302·1 |
| 3 | 159·98 | 1·47 | 6·85 | 3·31 | 7·61 | 295·9 |
| 4 | 172·18 | +1·47 | +6·17 | +1·99 | 6·48 | 287·9 |
| 14 | 294·48 | +1·50 | −5·07 | −6·33 | 8·10 | 141·5 |
| 15 | 306·72 | 1·51 | 5·48 | 5·82 | 7·97 | 136·7 |
| 16 | 318·96 | 1·51 | 5·70 | 5·01 | 7·57 | 131·3 |
| 17 | 331·19 | 1·51 | 5·77 | 3·93 | 6·97 | 124·3 |
| 18 | 343·41 | 1·52 | 5·63 | 2·61 | 6·20 | 114·9 |
| 19 | 355·63 | +1·52 | −5·27 | −1·12 | 5·39 | 102·0 |
| 20 | 7·85 | 1·52 | 4·66 | +0·46 | 4·68 | 84·4 |
| 21 | 20·06 | 1·53 | 3·79 | 2·04 | 4·30 | 61·7 |
| 22 | 32·26 | +1·53 | −2·66 | +3·52 | 4·41 | 37·0 |

| Greenwich Noon. | Selenographical Colong. of the Sun. | Lat. | Geocentric Libration. Sel. Long. of the Earth. | Lat. | Combined Amount. | Direction. |
|---|---|---|---|---|---|---|
| 1896. | ° | ° | ° | ° | ° | ° |
| May 23 | 44·45 | +1·53 | −1·28 | +4·80 | 4·97 | 14·9 |
| 24 | 56·64 | +1·53 | +0·26 | +5·77 | 5·78 | 357·4 |
| 25 | 68·83 | 1·53 | 1·86 | 6·36 | 6·63 | 343·8 |
| 26 | 81·01 | 1·52 | 3·39 | 6·53 | 7·35 | 332·7 |
| 27 | 93·20 | 1·52 | 4·68 | 6·28 | 7·83 | 323·5 |
| 28 | 105·38 | 1·51 | 5·65 | 5·64 | 7·97 | 315·1 |
| 29 | 117·57 | +1·51 | +6·20 | +4·69 | 7·77 | 307·2 |
| 30 | 129·76 | 1·50 | 6·30 | 3·52 | 7·21 | 299·3 |
| 31 | 141·96 | 1·49 | 5·97 | 2·19 | 6·36 | 290·2 |
| June 1 | 154·17 | 1·48 | 5·26 | +0·79 | 5·32 | 278·6 |
| 2 | 166·38 | 1·48 | 4·23 | −0·61 | 4·28 | 261·8 |
| 3 | 178·59 | +1·47 | +3·02 | −1·96 | 3·60 | 237·0 |
| 13 | 301·00 | +1·37 | −4·79 | −4·04 | 6·26 | 130·2 |
| 14 | 313·25 | 1·36 | 4·52 | 2·71 | 5·27 | 121·0 |
| 15 | 325·49 | 1·35 | 4·09 | −1·21 | 4·26 | 106·5 |
| 16 | 337·72 | 1·35 | 3·52 | +0·38 | 3·54 | 83·8 |
| 17 | 349·95 | 1·34 | 2·80 | 1·96 | 3·42 | 55·0 |
| 18 | 2·18 | +1·33 | 1·94 | 3·44 | 3·95 | 29·4 |
| 19 | 14·40 | 1·32 | −0·93 | 4·73 | 4·82 | 11·3 |
| 20 | 26·61 | 1·30 | +0·19 | 5·72 | 5·72 | 358·1 |
| 21 | 38·81 | 1·29 | 1·38 | 6·37 | 6·52 | 347·8 |
| 22 | 51·01 | 1·27 | 2·56 | 6·61 | 7·09 | 338·9 |
| 23 | 63·21 | +1·26 | +3·65 | +6·45 | 7·41 | 330·6 |
| 24 | 75·40 | 1·24 | 4·55 | 5·89 | 7·44 | 322·5 |
| 25 | 87·59 | 1·22 | 5·17 | 5·00 | 7·19 | 314·2 |
| 26 | 99·78 | 1·20 | 5·46 | 3·85 | 6·67 | 305·3 |
| 27 | 111·97 | 1·18 | 5·39 | 2·52 | 5·99 | 295·1 |
| 28 | 124·17 | +1·16 | +4·96 | +1·09 | 5·08 | 282·4 |
| 29 | 136·37 | 1·14 | 4·21 | −0·36 | 4·23 | 265·1 |
| 30 | 148·57 | 1·12 | 3·20 | 1·76 | 3·65 | 241·2 |
| July 1 | 160·78 | 1·10 | 2·10 | 3·07 | 3·72 | 214·3 |
| 2 | 173·00 | 1·08 | +0·79 | 4·23 | 4·30 | 190·4 |
| 3 | 185·22 | +1·06 | −0·64 | −5·20 | 5·24 | 173·0 |
| 13 | 307·68 | +0·87 | −2·88 | +0·13 | 2·88 | 87·4 |
| 14 | 319·92 | 0·85 | 1·93 | 1·78 | 2·63 | 47·3 |
| 15 | 332·16 | +0·83 | −0·91 | +3·32 | 3·44 | 15·3 |

| Greenwich Noon. | Selenographical Colong. of the Sun. | Lat. | Geocentric Libration. Sel. Long. of the Earth. | Lat. | Combined Amount. | Direction. |
|---|---|---|---|---|---|---|
| 1896. | ° | ° | ° | ° | ° | ° |
| July 16 | 344·39 | +0·81 | +0·14 | +4·64 | 4·64 | 358·3 |
| 17 | 356·62 | 0·79 | 1·19 | 5·72 | 5·84 | 348·2 |
| 18 | 8·84 | 0·77 | 2·21 | 6·42 | 6·79 | 341·1 |
| 19 | 21·05 | +0·75 | +3·15 | +6·73 | 7·43 | 335·0 |
| 20 | 33·26 | 0·72 | 3·97 | 6·64 | 7·73 | 329·3 |
| 21 | 45·46 | 0·70 | 4·61 | 6·16 | 7·69 | 323·3 |
| 22 | 57·66 | 0·67 | 5·05 | 5·34 | 7·34 | 316·7 |
| 23 | 69·85 | 0·64 | 5·24 | 4·24 | 6·74 | 309·1 |
| 24 | 82·04 | 0·62 | 5·16 | 2·94 | 5·94 | 299·7 |
| 25 | 94·23 | +0·59 | +4·80 | 1·53 | 5·03 | 287·5 |
| 26 | 106·42 | 0·56 | 4·17 | +0·03 | 4·17 | 270·4 |
| 27 | 118·61 | 0·53 | 3·30 | −1·43 | 3·60 | 246·6 |
| 28 | 130·81 | 0·50 | 2·23 | 2·79 | 3·57 | 218·6 |
| 29 | 143·01 | 0·48 | +1·01 | 4·02 | 4·14 | 194·1 |
| 30 | 155·22 | 0·45 | −0·29 | 5·06 | 5·07 | 176·7 |
| 31 | 167·43 | +0·42 | 1·61 | −5·88 | 6·10 | 164·7 |
| Aug. 1 | 179·64 | 0·39 | 2·86 | 6·46 | 7·06 | 156·2 |
| 2 | 191·86 | 0·37 | 3·97 | 6·75 | 7·83 | 149·7 |
| 3 | 204·09 | 0·34 | 4·88 | 6·75 | 8·33 | 144·3 |
| 4 | 216·32 | 0·31 | 5·51 | 6·44 | 8·47 | 139·6 |
| 5 | 228·56 | 0·29 | 5·83 | 5·79 | 8·21 | 134·9 |
| 6 | 240·80 | +0·27 | −5·79 | −4·83 | 7·54 | 129·9 |
| 7 | 253·04 | 0·24 | 5·40 | 3·57 | 6·47 | 123·5 |
| 8* | 265·29 | 0·22 | 4·66 | 2·07 | 5·10 | 114·0 |
| 9 | 277·54 | +0·20 | −3·63 | −0·40 | 3·65 | 96·3 |

* During the Eclipse of Aug. 8 the selenographical longitude Λ and latitude B of the point in the centre of the shadow cone and the position-angle P of the Moon's axis will be

| | h | | | |
|---|---|---|---|---|
| Aug. 8 | 16 Gr. | Λ = −3°·45 | B = −0°·21 | P = 16°·10 |
| | 18 | −4·48 | −0·20 | 16·12 |
| | 20 | −5·51 | −0·20 | 16·14 |

To find the selenographical longitude λ and latitude β of a point on the Moon's rim in position-angle $p$, it will not be worth while to take the semidiameter or the latitude B into account, so that λ and β are simply given, if

$p - P$ is between 0° and 180°, by $\lambda = \Lambda - 90°$ and $\beta = 90° - (p - P)$,

and if

$p - P$ is between 180° and 360°, by $\lambda = \Lambda + 90°$ and $\beta = p - P - 270°$.

The position-angle of the axis of the Sun during the eclipse will be 14°·07, and the heliographical latitude of the centre of the disc + 6°·40.

| Greenwich Noon. | Selenographical Colong. of the Sun. | Lat | Geocentric Libration. Sel. Long. of the Earth. | Lat. | Combined Amount. | Direction. |
|---|---|---|---|---|---|---|
| 1856. | ° | ° | ° | ° | ° | ° |
| Aug. 10 | 289·79 | +0·17 | −2·38 | +1·34 | 2·73 | 60·6 |
| 11 | 302·04 | 0·15 | −0·98 | 2·96 | 3·12 | 18·3 |
| 12 | 314·28 | +0·13 | +0·46 | +4·41 | 4·43 | 354·1 |
| 13 | 326·51 | 0·10 | 1·87 | 5·58 | 5·88 | 341·5 |
| 14 | 338·74 | 0·08 | 3·14 | 6·37 | 7·10 | 333·9 |
| 15 | 350·95 | 0·05 | 4·23 | 6·77 | 7·98 | 328·1 |
| 16 | 3·18 | +0·03 | 5·08 | 6·75 | 8·44 | 323·2 |
| 17 | 15·39 | 0·00 | 5·66 | 6·34 | 8·49 | 318·4 |
| 18 | 27·59 | −0·03 | +5·97 | +5·60 | 8·18 | 313·3 |
| 19 | 39·78 | 0·06 | 6·01 | 4·56 | 7·54 | 307·3 |
| 20 | 51·97 | 0·09 | 5·79 | 3·30 | 6·66 | 299·8 |
| 21 | 64·16 | 0·12 | 5·33 | 1·91 | 5·66 | 289·7 |
| 22 | 76·34 | 0·15 | 4·65 | +0·44 | 4·67 | 275·4 |
| 23 | 88·53 | 0·18 | 3·77 | −1·02 | 3·91 | 254·8 |
| 24 | 100·71 | −0·21 | +2·75 | 2·42 | 3·66 | 228·6 |
| 25 | 112·89 | 0·24 | 1·57 | 3·70 | 4·02 | 203·0 |
| 26 | 125·08 | 0·27 | +0·31 | 4·80 | 4·81 | 183·6 |
| 27 | 137·27 | 0·30 | −1·01 | 5·68 | 5·77 | 169·9 |
| 28 | 149·46 | 0·33 | 2·33 | 6·33 | 6·74 | 159·9 |
| 29 | 161·66 | 0·36 | 3·57 | 6·70 | 7·59 | 152·1 |
| 30 | 173·86 | −0·38 | −4·70 | −6·79 | 8·27 | 145·5 |
| 31 | 186·06 | 0·41 | 5·65 | 6·57 | 8·66 | 139·5 |
| Sept. 1 | 198·27 | 0·43 | 6·34 | 6·04 | 8·75 | 133·8 |
| 2 | 210·49 | 0·46 | 6·72 | 5·21 | 8·49 | 127·9 |
| 3 | 222·72 | 0·48 | 6·72 | 4·07 | 7·85 | 121·3 |
| 4 | 234·95 | 0·50 | 6·31 | 2·68 | 6·85 | 113·1 |
| 5 | 247·18 | −0·52 | −5·48 | −1·08 | 5·58 | 101·2 |
| 13 | 345·01 | −0·70 | +6·60 | +6·40 | 9·19 | 314·3 |
| 14 | 357·21 | 0·73 | 7·12 | 5·71 | 9·12 | 308·9 |
| 15 | 9·41 | 0·76 | 7·26 | 4·73 | 8·66 | 303·2 |
| 16 | 21·60 | 0·78 | 7·04 | 3·53 | 7·87 | 296·7 |
| 17 | 33·79 | 0·81 | 6·53 | 2·18 | 6·88 | 288·5 |
| 18 | 45·97 | −0·83 | +5·78 | +0·75 | 5·83 | 277·4 |
| 19 | 58·14 | 0·86 | 4·82 | −0·70 | 4·87 | 261·7 |
| 20 | 70·31 | 0·89 | 3·73 | 2·09 | 4·27 | 240·7 |
| 21 | 82·48 | 0·91 | 2·53 | 3·37 | 4·21 | 216·9 |
| 22 | 94·65 | −0·94 | +1·27 | −4·50 | 4·68 | 195·7 |

| Greenwich Noon. | Selenographical Colong. of the Sun. | Selenographical Lat. of the Sun. | Geocentric Libration. Sel. Long. of the Earth. | Geocentric Libration. Lat. of the Earth. | Geocentric Libration. Combined Amount. | Direction. |
|---|---|---|---|---|---|---|
| 1896. | ° | ° | ° | ° | ° | ° |
| Sept. 23 | 106·82 | −0·96 | −0·03 | −5·42 | 5·42 | 179·7 |
| 24 | 118·99 | 0·99 | 1·34 | 6·11 | 6·25 | 167·7 |
| 25 | 131·16 | 1·01 | 2·62 | 6·53 | 7·04 | 158·2 |
| 26 | 143·33 | 1·03 | 3·85 | 6·68 | 7·70 | 150·2 |
| 27 | 155·51 | 1·05 | 4·98 | 6·53 | 8·21 | 142·8 |
| 28 | 167·69 | −1·07 | −5·96 | −6·09 | 8·51 | 135·8 |
| 29 | 179·88 | 1·09 | 6·72 | 5·35 | 8·59 | 128·7 |
| 30 | 192·08 | 1·10 | 7·19 | 4·34 | 8·40 | 121·2 |
| Oct. 1 | 204·28 | 1·12 | 7·32 | 3·08 | 7·94 | 112·9 |
| 2 | 216·48 | 1·14 | 7·04 | −1·61 | 7·22 | 102·9 |
| 3 | 228·69 | −1·15 | −6·31 | 0·00 | 6·31 | 90·0 |
| 13 | 350·82 | −1·30 | +8·01 | +3·64 | 8·80 | 294·6 |
| 14 | 3·00 | 1·32 | 7·72 | 2·31 | 8·06 | 286·7 |
| 15 | 15·18 | 1·33 | 7·07 | +0·90 | 7·13 | 277·3 |
| 16 | 27·35 | 1·35 | 6·15 | −0·52 | 6·17 | 265·2 |
| 17 | 39·52 | 1·37 | 5·03 | 1·90 | 5·38 | 249·3 |
| 18 | 51·68 | 1·38 | 3·80 | 3·17 | 4·95 | 230·1 |
| 19 | 63·83 | −1·40 | 2·50 | 4·29 | 4·97 | 210·2 |
| 20 | 75·99 | 1·41 | +1·18 | −5·22 | 5·35 | 192·7 |
| 21 | 88·14 | 1·42 | −0·12 | 5·92 | 5·93 | 178·8 |
| 22 | 100·29 | 1·43 | 1·39 | 6·37 | 6·52 | 167·7 |
| 23 | 112·44 | 1·44 | 2·60 | 6·54 | 7·04 | 158·4 |
| 24 | 124·59 | 1·45 | 3·74 | 6·43 | 7·44 | 149·9 |
| 25 | 136·75 | −1·46 | −4·79 | −6·02 | 7·69 | 141·6 |
| 26 | 148·91 | 1·47 | 5·71 | 5·33 | 7·80 | 133·2 |
| 27 | 161·07 | 1·47 | 6·45 | 4·38 | 7·79 | 124·3 |
| 28 | 173·24 | 1·48 | 6·97 | 3·20 | 7·67 | 114·7 |
| 29 | 185·41 | 1·48 | 7·20 | 1·83 | 7·43 | 104·3 |
| 30 | 197·59 | 1·49 | 7·08 | −0·32 | 7·09 | 92·6 |
| 31 | 209·78 | −1·49 | −6·54 | +1·25 | 6·66 | 79·2 |
| Nov. 10 | 331·77 | −1·52 | +7·91 | +2·44 | 8·28 | 287·2 |
| 11 | 343·95 | 1·52 | 7·67 | +1·01 | 7·74 | 277·5 |
| 12 | 356·12 | 1·52 | 7·04 | −0·43 | 7·05 | 266·5 |
| 13 | 8·29 | 1·53 | 6·09 | 1·81 | 6·35 | 253·4 |
| 14 | 20·45 | 1·53 | 4·94 | 3·09 | 5·83 | 237·9 |
| 15 | 32·61 | −1·53 | +3·66 | −4·22 | 5·58 | 220·9 |

| Greenwich Noon. | Selenographical Colong. of the Sun. | Lat. | Geocentric Libration. Sel. Long. of the Earth. | Lat. | Combined Amount. | Direction. |
|---|---|---|---|---|---|---|
| 1896. | ° | ° | ° | ° | ° | ° |
| Nov. 16 | 44·76 | −1·53 | +2·32 | −5·15 | 5·65 | 204·2 |
| 17 | 56·90 | 1·53 | +1·00 | 5·86 | 5·94 | 189·6 |
| 18 | 69·04 | 1·52 | −0·27 | 6·32 | 6·33 | 177·6 |
| 19 | 81·18 | 1·52 | 1·46 | 6·51 | 6·67 | 167·4 |
| 20 | 93·31 | −1·52 | −2·55 | −6·41 | 6·90 | 158·4 |
| 21 | 105·45 | 1·51 | 3·53 | 6·01 | 6·97 | 149·7 |
| 22 | 117·59 | 1·50 | 4·40 | 5·33 | 6·91 | 140·6 |
| 23 | 129·73 | 1·50 | 5·13 | 4·39 | 6·75 | 130·7 |
| 24 | 141·87 | 1·49 | 5·71 | 3·23 | 6·56 | 119·6 |
| 25 | 154·02 | −1·48 | −6·11 | 1·88 | 6·39 | 107·1 |
| 26 | 166·17 | 1·47 | 6·29 | −0·41 | 6·30 | 93·7 |
| 27 | 178·33 | 1·45 | 6·20 | +1·12 | 6·30 | 79·7 |
| 28 | 190·49 | 1·44 | 5·78 | 2·62 | 6·34 | 65·6 |
| 29 | 202·66 | 1·43 | 4·99 | 4·00 | 6·39 | 51·2 |
| 30 | 214·84 | −1·42 | −3·84 | +5·17 | 6·44 | 36·5 |
| Dec. 10 | 336·71 | −1·31 | +6·29 | −1·67 | 6·51 | 255·1 |
| 11 | 348·88 | 1·30 | 5·42 | 3·01 | 6·20 | 240·9 |
| 12 | 1·04 | 1·29 | 4·31 | 4·18 | 6·00 | 225·8 |
| 13 | 13·20 | 1·28 | 3·06 | 5·15 | 5·99 | 210·6 |
| 14 | 25·35 | 1·26 | 1·75 | 5·90 | 6·15 | 196·5 |
| 15 | 37·49 | 1·25 | +0·44 | 6·39 | 6·40 | 183·9 |
| 16 | 49·63 | −1·23 | −0·78 | −6·61 | 6·66 | 173·3 |
| 17 | 61·76 | 1·21 | 1·89 | 6·54 | 6·79 | 163·9 |
| 18 | 73·89 | 1·19 | 2·85 | 6·17 | 6·79 | 155·3 |
| 19 | 86·02 | 1·17 | 3·64 | 5·51 | 6·60 | 146·7 |
| 20 | 98·15 | 1·15 | 4·26 | 4·57 | 6·24 | 137·1 |
| 21 | 110·28 | 1·13 | 4·71 | 3·40 | 5·81 | 125·9 |
| 22 | 122·41 | −1·11 | −4·98 | −2·03 | 5·38 | 112·2 |
| 23 | 134·54 | 1·08 | 5·08 | −0·53 | 5·11 | 96·0 |
| 24 | 146·68 | 1·06 | 4·99 | +1·03 | 5·09 | 78·3 |
| 25 | 158·82 | 1·04 | 4·69 | 2·55 | 5·34 | 61·4 |
| 26 | 170·97 | 1·01 | 4·18 | 3·95 | 5·75 | 46·5 |
| 27 | 183·12 | 0·99 | 3·43 | 5·13 | 6·17 | 33·7 |
| 28 | 195·28 | −0·96 | −2·45 | +6·03 | 6·51 | 22·0 |

In resuming the preparation of ephemerides for physical observations of the Moon, the last of which for 1891 were

published in vol. 51, I have adopted 1°.523 as the inclination of the plane of the Moon's equator to the ecliptic instead of the former 1°·536, and I have also taken into account the chief term of the physical libration in longitude, which depends on the Sun's mean anomaly, and the coefficient of which Professor Franz has deduced from Schlüter's heliometrical measurements.

In vol. 51 pp. 164–176 may be found a list of published lunar sketches and photographs arranged according to the Sun's position. By means of the data in the first column, consisting of a constant and a factor to be multiplied into the Sun's selenographical latitude, the colongitude ($= 90° - \text{long.}$) is found which the Sun must reach in order to be at the same altitude above the horizon of the spot represented as at the assigned time of the sketch or photograph, so that, by reference to an ephemeris like the present one, it is easy to ascertain the corresponding times in any lunation to about a minute. I am desirous to make a general list of photographs and sketches which have either been published or are at least accessible in the library of the Royal Astronomical Society, and I want to arrange them so that observers may easily ascertain beforehand, whenever they prepare for observing, what recurring phenomena they may look for and also what regions require to be observed. But such a general list can only be prepared for those photographs and sketches which have been properly timed, and it is a very curious and regrettable fact that, while some sketchers, instead of making sure and stating the times when the chief shadows were drawn, which are the times required, merely mention the hours or half-hours between which their drawings were made, there are still published lunar photographs without the slightest indication of the times when they were taken.

Enlarged photographs, even imperfect ones, supply at once a great amount of trustworthy information about the shadow-throwing, which, if duly made use of, relieves observers even of attempts at observing in the glare of the light so injurious to the eyes, so that they may devote themselves entirely to observations of details in a confined field, and at the most suitable occasions. Take the case of the beautiful photographs published in *Knowledge*, and therefore in the possession of or accessible to many observers. How much interesting information about the whole region from Macrobius to Plinius northward to the rim is contained in that published in the number for 1894 April, and what an amount is stored up about the region from Aliacensis to Manilius, and from Tacitus to Ptolemæus in the photograph "Sunrise on Ptolemæus," published in the number for 1894 December! But at present the greater part of the valuable evidence of these photographs is locked up and not available, simply because the key to it is withheld. No inkling, even, is to be found, in the articles accompanying the photographs, of the times when they were taken, and hitherto I have tried in vain to obtain them.

If, instead of a plain statement of the time, to the hour and

minute, and what time is meant, the age of the Moon or the time elapsed since New Moon is given to the hour, what purpose is that intended to serve? Is there any need to point out that the age of the Moon affords only a rough indication of the state of illumination, which one wants to know? That depends on the Sun's position referred to selenographical coordinates. According to the present ephemeris the Sun's centre will be in selenographical longitude + 90° and − 90°, or in colong. 0° and 180° at the following times, to which are added the corresponding ages of the Moon in hours and to the minute :—

| 1896. | ☉'s col. 0°. h m | Moon's age. h m | | ☉'s col. 180°. h m | Moon's age. h m |
|---|---|---|---|---|---|
| Jan. 22 | 4 28 | 186 9 | Feb. 6 | 0 14 | 541 55 |
| Feb. 20 | 18 44 | 182 31 | Mar. 6 | 14 10 | 537 57 |
| Mar. 21 | 8 15 | 177 27 | Apr. 5 | 3 14 | 532 26 |
| Apr. 19 | 20 50 | 172 27 | May 4 | 15 23 | 527 0 |
| May 19 | 8 35 | 168 49 | June 3 | 2 46 | 523 0 |
| June 17 | 19 43 | 167 0 | July 2 | 13 45 | 521 2 |
| July 17 | 6 38 | 167 3 | Aug. 1 | 0 42 | 521 7 |
| Aug. 15 | 17 45 | 168 43 | 30 | 12 5 | 523 3 |
| Sept. 14 | 5 29 | 171 46 | Sept. 29 | 0 14 | 527 31 |
| Oct. 13 | 18 5 | 175 47 | Oct. 28 | 13 20 | 531 2 |
| Nov. 12 | 7 39 | 180 12 | Nov. 27 | 3 18 | 535 51 |
| Dec. 11 | 21 57 | 184 6 | Dec. 26 | 17 50 | 539 59 |

In *Knowledge* for 1895 June representations of Maurolycus and Albategnius are published from a photograph taken at Paris 1894 March 14, $6^h\ 33^m\ 57^s$, Paris mean time, so that it is feasible to compute the data for the list, the Sun's zenith distance at the assigned time being found to have been 78°·09 at Maurolycus A and 87°·70 at Albategnius *A*.

For computing the data for the photographs of Copernicus, published in the *Harvard Annals*, vol. xxxii. p. 1, Plate V., and in vol. iii. of the *Publications of the Lick Observatory*, the positions of the Sun derived from my old ephemerides require merely the small corrections due to the physical libration and to the alteration of the inclinations, and give the zenith distances of the Sun at the central mountain of Copernicus 1889 September 4, $18^h\ 6^m$, Greenwich mean time, 77°·25 ; 1891 July 28, $15^h\ 49^m\ 16^s$, Pac. stand. time, 80°·39 ; and 1891 October 12, $7^h\ 50^m\ 54^s{\cdot}5$, Pac. stand. time, 75°·98. Hence we get for due insertion in the list and for finding the times of recurrences :

| Sun's Colong. | Sun's Col. | Sun's Lat. | Spot. | | |
|---|---|---|---|---|---|
| $2°{\cdot}45 + 0{\cdot}202 \times$ ☉'s lat. | $2°{\cdot}36$ | $-0°{\cdot}46$ | Albategnius | 1894 Mar. 14 | Paris |
| $2{\cdot}81 + 0{\cdot}986$ ,, | $2{\cdot}36$ | $-0{\cdot}46$ | Maurolycus | 1894 Mar. 14 | Paris |
| $32{\cdot}86 - 0{\cdot}169$ ,, | $32{\cdot}63$ | $+1{\cdot}37$ | Copernicus | 1889 Sept. 4 | Harvard |
| $34{\cdot}14 - 0{\cdot}170$ ,, | $33{\cdot}98$ | $+0{\cdot}97$ | Copernicus | 1891 Oct. 12 | Lick |
| $190{\cdot}19 + 0{\cdot}167$ ,, | $190{\cdot}42$ | $+1{\cdot}37$ | Copernicus | 1891 July 28 | Lick |

I am willing to extend these computations to all published or to-be-published photographs, and to the most interesting spots upon them, and also to all duly timed published sketches. But for the purpose I require to be supplied with lists of the times when the photographs were taken, and when the chief shadows on the sketches were drawn, as also due references to the publications where they are to be found, so that, in case I get the opportunity, I may refer to them and consult them in the library of the Royal Astronomical Society.

I will conclude with giving for a few sketches the predictions of the times when the Sun will reach, at the spots represented, the same zenith distance as at the assigned times, and I select for the purpose the sketches published in the *Memoirs of the British Astronomical Association*, vol. iii. part v. or Plates IV. to VII., and therefore easily accessible. The data for these sketches are :

| Sun's Colong. | | Sun's Colong. | Sun's Lat. | Spot. | | | h | m | |
|---|---|---|---|---|---|---|---|---|---|
| 332°·50 + 0·560 × | ⊙'s lat. | 331°·86 | −1°·14 | Piccolomini | 1892 Jan. | 4 | 5 | 15 | Elger |
| 337·15 + 0·201 | ,, | 337·17 | +0·07 | Theophilus | 1893 Apr. | 21 | 8 | 42·5 | Gordon |
| 338·28 + 0·201 | ,, | 338·48 | +1·00 | ,, | 1894 May | 20 | 8 | 15 | Mee |
| 7·75 + 0·390 | ,, | 8·09 | +0·88 | Thebit & Wall | 1893 May | 23 (not 24) | 9h | 10m | [Corder |
| 126·87 − 0·035 | ,, | 126·82 | −1·27 | Messier | 1894 Nov. | 15 | 11 | 30 | Mee |
| 138·51 − 0·567 | ,, | 139·01 | −0·85 | Piccolomini | 1891 Dec. | 19 | 11 | 0 | Elger |

*Times of Recurrences.*

| | Piccolomini. 332°·50 +0·560 lat. h m | Theophilus. 337° 15 +·201 lat. h m | Thebit. 7°·75 +·390 lat. h m | | Messier. 126°·87 −·035 lat. h m | | Piccolomini 138°·51 −0·567 lat. h m |
|---|---|---|---|---|---|---|---|
| Feb. | 18 12 29 | 18 21 39 | 21 9 59 | Mar. | 2 5 19 | Mar. | 3 4 3 |
| Mar. | 19 2 51 | 19 11 31 | 22 0 5 | | 31 18 27 | Apr. | 1 16 13 |
| Apr. | 17 16 11 | 18 0 26 | 20 13 5 | | 30 6 42 | May | 1 4 8 |
| May | 17 4 15 | 17 12 18 | 20 0 59 | | 29 18 13 | | 30 15 35 |
| June | 15 15 15 | 15 23 25 | 18 11 58 | | 28 2 28 | June | 29 2 58 |
| July | 15 1 35 | 15 10 6 | 17 22 27 | | 28 16 13 | July | 28 14 38 |
| Aug. | 13 11 51 | 13 20 55 | 16 9 0 | | 26 3 33 | Aug. | 27 2 49 |
| Sept. | 11 22 40 | 12 8 16 | 14 20 9 | | 23 15 37 | Sept. | 25 15 39 |
| Oct. | ... | ... | 14 8 20 | | 24 4 35 | Oct. | 25 5 9 |
| Nov. | 9 23 46 | 10 10 1 | 12 21 45 | | 22 18 27 | Nov. | 23 19 4 |
| Dec. | 9 14 15 | 10 0 21 | 12 12 15 | | 22 8 54 | Dec. | 23 9 6 |

It will be worth while watching on February 18 for the time of the first sunlight on the central mountain of Piccolomini, but especially on February 21, watching and timing the phenomena of sunrise over Purbach, Thebit, and the long Wall. But the suggestion must be sufficient.

*Col. Cooper's Observatory,*
*Markree, Collooney, Ireland.*

*Errata in Mr. Barnard's Paper.*

Vol. lvi. page 58, 3rd line from bottom, *for* Bruno *read* Bruhns.
„ 59, 5th, 10th, and 15th lines from top, *for* Bruno *read* Bruhns.